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STUDY TO IMPROVE THE STARTING PROBABILITY OF LIFEBOAT DIESEL EN--ETC(U)

FEB 79 R M DIJULIO, R SAUCEDO DOT-CG-74133-A

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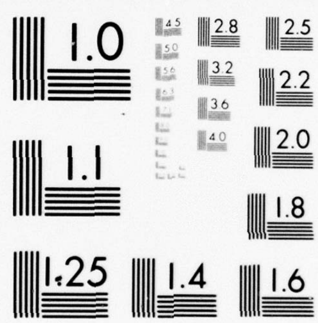

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STUDY TO IMPROVE THE STARTING PROBABILITY OF LIFEBOAT DIESEL ENGINES

FEBRUARY 1979

FINAL REPORT

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U.S. DEPARTMENT OF TRANSPORTATION
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The U.S. Coast Guard project leader for this study was LCDR S.H. Davis

16. Abstract

This report presents the results of a study to find a state-of-the-art solution to the cold starting problem of lifeboat diesel engines. The cold starting problem is phrased in a two-tier objective, namely:

1) being able to start the engine reliably at -22°F using starting aids and ship's power, and
2) starting the diesel engines reliably at ambient temperatures when ship's power is not available.

The study was conducted in two parts: a state-of-the-art survey and a system design and laboratory testing program.

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PREFACE

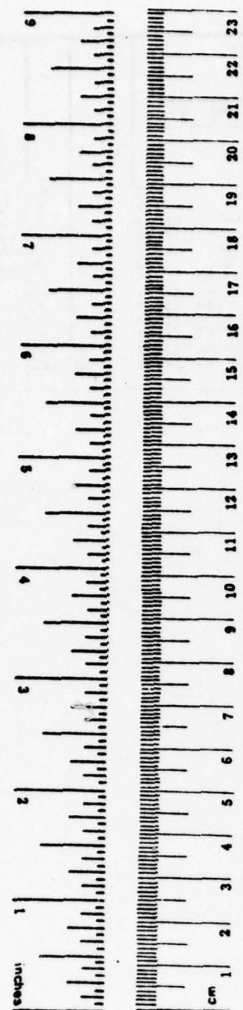
This report summarizes work conducted under Contract No.DOT-CG-74133-A by CASDE Corporation under the auspices of the U.S. Coast Guard, with LCdr. S.H. Davis serving as project leader. The program manager was Dr. R. Saucedo. Mr. R.M. DiJulio served as the principal investigator.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

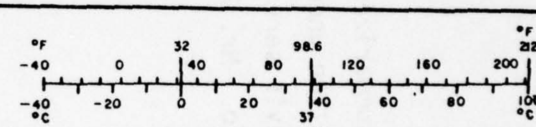


FIGURE 3. METRIC CONVERSION FACTORS

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1. INTRODUCTION

Lifeboats are normally stowed above the main deck and subject to the elements. As consequence, in coldweather, air and diesel engine temperatures are often so low that engine compression does not sufficiently heat the air charge to ignite the fuel. A lifeboat engine is therefore difficult to start under these conditions. Moreover the normal and preventative engine maintenance needed to assure reliable starts is often casual or neglected entirely.

The U.S. Coast Guard contracted CASDE Corporation to perform a study to find state-of-the-art solutions to the cold-start problem and to determine measures which minimize the need for maintenance. Replacement of existing engines with units especially designed for cold starts and low maintenance was not considered because of the economics involved. The problem could be solved by retrofitting existing engines with commercially available equipment, lubricants, and other aids. New lifeboats could be required to have appropriately equipped engines as a condition for Coast Guard approval.

This report is presented in two parts; Part 1 presents the results of the state-of-the-art survey: Part II presents the results of the system design and laboratory testing program.

1.1 Two-Tier Objective

It should be noted that the cold starting problem, in reality has a dual temperature objective. Consider that the need for immediate engine starts occur during man-overboard or abandon-ship operations. In either case the engine is started at ambient temperature while in the davit. Ship's service power, if needed to aid in starting, is available.

Once in the water however, the applications differ. A rescue operation will proceed until the man overboard is retrieved or the search is abandoned. The engine is not normally turned-off until the boat is recovered aboard ship. In abandon-ship operations, once clear of the ship, the engine may be secured to conserve fuel and await rescue.

These conditions led to a dual objective for this program: 1) to reliably start an engine at -22^{o}F with the use of aids and ship's power and 2) to start the same engine, with only the aids contained in the boat and without ship's power, at ambient temperatures of approximately +20^{o}F.

1.2 Results of the State-of-the-Art Survey: Part I

The survey consisted of a review of the literature and the results of past investigations. It also included correspondence and interviews with engine manufacturers, suppliers, and users from various fields, including: construction, truck transportation, stationary power plants, aviation, rail transportation, the petroleum industry, and of course maritime applications. The interviews were conducted by telephone, visits to supplier's and user's facilities, and vendor visits to CASDE Corporation offices.

The survey sought promising devices and commodities which could be easily retrofitted to existing engines. Particular suppliers known to be active in these areas of interest were contacted for performance and logistic suitability, effectiveness, reliability, and maintainability. Particular systems, commodities, and devices were then obtained for test and evaluation during Part II phase of the study.

It is noteworthy that engine manufacturers, with minor exceptions, are not particularly active in trying to solve the cold-weather starting problem, probably because of the limited market involved. A few, however, did provide data sheets describing how their engines could be out-fitted to start at low temperatures. This information was found to be relevant and useful.

Another useful source of relevant work and experience was found in technical papers reporting results of investigations by various government agencies. The most definitive work was done by the U.S. Navy over twenty-five years ago. It's noteworthy that little or no work has been reported since by any Federal Agency.

Aside from improvements in fuels, lubricants, additives and devices offered by the petroleum and truck accessories industries, the state-of-the-art is at least twenty-five years old. CASDE Corporation concluded, however, that sufficient material, information and sources existed to obtain the necessary equipment to assemble a system for cold-chamber evaluation.

2. SOURCES AND SUPPLIERS SOLICITED

The sources and suppliers solicited during the course of the Survey are listed below.

2.1 Batteries and Charging Systems

1. Gulton Industries, Inc.
   Hawthorne, CA
2. General Electric Company
   Battery Business Department
   Gainesville, Florida
3. The Surrette Storage Battery Co.
   Salem, Massachusetts
4. C&D Batteries
   Plymouth Meeting, Pennsylvania
5. EXXIDE Power Systems
   Santa Fe Springs, CA
6. Union Carbide Corp.
   Battery Products Division
   New York, N.Y.

7. Nife Inc.
   Lincoln, R.I.
8. Gould Inc.
   Langhorne, Pa.
9. SGL Batteries Mfg. Co.
   Detroit, Michigan
10. Stored Energy Systems
    Mountain View, CA
11. SES Solar Energy Systems, Inc.
    Newark, Delaware
12. Marine Development Corporation
    Richmond, Virginia
13. Teledyne Inet
    Gardena, CA
14. Marine Electric R.P.D. Inc.
    Edison, N.J.
15. Dynamic Instruments Corp.
    Hauppage, N.Y.

2.2 Starting Systems, Starters and Aids

1. Ingersoll-Rand Engine Starting Systems
   Desplaines, Illinois
2. Stewart & Stevenson Services Inc.
   Dallas, Texas
3. CAV Limited
   London, England
4. SIMMS Motor Units Limited
   London, England
5. Lucas Service, Lucas Industries, Inc.
   Troy, Michigan
6. Bryce Berger Limited
   Gloucester, England
7. American Bosch Division
   Springfield, Massachusetts
8. Mar-Oil Hydraulics, Inc.
   Hoboken, N.J.
9. AiResearch Mfg. Co.
   Los Angeles, CA
10. Holsclaw Bros., Inc.
    Evansville, Indiana
11. Delco-Remy Division
    Anderson, Ind.
12. KIM Hotstart Mfg. Co.
    Spokane, Washington
13. Turner Corporation
    Cleveland, Ohio

2.3 Engine Manufacturers and Suppliers

1. Hawthorne Engine Systems
   San Diego, California
2. Caterpillar Tractor Company
   Peoria, Illinois
3. Farymann Diesel
   Lampertheim, Federal Republic of Germany
4. AiResearch Manufacturing Company of California
   Torrance, California
5. Colt Industries
   Fairbank Morse Engine Division
   Beloit, Wisconsin
6. Perkins Engines, Inc.
   Peterborough, England
7. J.H. Westerbeke Corp.
   Avon, Massachusetts
8. White Engines Inc.
   Canton, Ohio
9. Renault Marine
   Fort Lauderdale, Florida
10. Lister Diesels Inc.
    555 East 56 Hiway, P.O. Box 386
    Olathe Kansas and
    Gloucester, England
11. Yanmar Diesel Engine Co., LTD
    Tokyo, Japan
12. Volvo Penta
    Goteborg, Sweden
13. C.E. Smith Co., Inc.
    Newport Beach, CA
14. Cummins Engines Co., Inc.
    Columbus, Ind.
15. Ford Motor Co.
    Livonia, Mich.
16. Deutz Diesel Corp.
    Hicksville, N.Y.
17. Detroit Diesel Engine Division
    Detroit, Mich.
18. International Harvestor Co.
    Melrose Park, Ill.

2.4 Lubricants, Fuels, and Additives

1. M & M Synthetic Lubricants, Inc.
   Ft. Lauderdale, Florida
2. Mobil Oil Corporation
   New York, N.Y. and
   Los Angeles, CA
3. LPS Research Laboratories Inc.
   Los Angeles, CA
4. Shell Oil Co.
   Houston, Texas
5. TEXACO, Inc.
   New York, N.Y.
6. Gulf Oil Co.
   Houston, Texas
7. EXXON Co.
   Houston, Texas
8. Union Oil Co.
   Orange, CA

2.5 Lifeboat Manufacturers and Other Users

1. Whittaker Corp.
   La Mesa, CA
2. Watercraft America, Inc.
   Mims, Florida
3. Marine Safety Equipment Corp
   Farmingdale, N.J.
4. Lane Marine Technology Inc.
   Brooklyn, N.Y.
5. Bechtel Constructors, Inc.
   San Francisco, CA
6. Fluor Corp.
   Los Angeles, CA
7. Naval Ship Engineering Center
   Crystal City, VA
8. U.S. Army Mobility Equipment R&D Command
   Ft. Belvoir, VA
9. Kings Point Machinery
   San Francisco, CA

3. ASSESSMENT OF TECHNOLOGY, PRODUCTS

The survey included a literature search and numerous discussions with experienced engine manufacturers and users in a variety of fields. These discussions proved to be both illuminating and disappointing at the same time; the disappointment stemmed from two facts: 1) very little basically new work has been done over the past 25 to 30 years, and 2) the manufacturers have not been strongly motivated to seeking solutions for the lifeboat engine cold-starting problem. It was found, however, that new approaches in the design of starting systems, batteries, oils, charging systems, intake injection systems, and engine heaters have been developed in the ensuing years.

3.1 Engine Manufacturer Survey

It was found, as one might expect, that manufacturers of Coast Guard approved lifeboat engines tended to elaborate on features of their products. Manufacturers of accessories, fuels, and lubricants appeared to be more general and candid about existing methodology. All respondants however, were quite helpful and willing to share their experience.

The concensus of opinion thus gathered was as follows:

1) Low viscosity lube-oil should be used. Artic grade SAE 5W weight or the equivalent was strongly recommended. None of the manufacturers had any experience with the newer synthetic oils.
2) Careful attention must be given to the grade of fuel used. It was stressed that this is a commonly over-looked item aboard ships and the source of trouble. Artic-grade fuels were strongly recommended; winter-grade fuels were not felt to be adequate. It was stressed that not only is the Cetane number and pour point important but also the cloud point. Most manufacturers pointed out that they normally provide specifications for fuel but that these are often ignored.

The use of Cetane additives to the fuel was not recommended for the lifeboat engine application; their experience is that it tends to separate from the fuel unless there is a steady agitation. All manufacturers suggested heating of the fuel. It should be noted however that CASDE Corporation tests showed that heating is not necessary if the fuel is properly selected.

3) Means to temporarily increase the engine compression ratio during the starting process are desireable. All of the Coast Guard approved engines have a manual feature to accomplish this. One of the engines manufacturers motivated by this study, developed an automatic decompression system to facilitate cranking.

4) Means to provide high-power, long-endurance cranking systems are essential. Manual starting methods were quickly ruled out as a primary starting means. Expressed preference was an electric system of 24 volts or higher; the mean current drawn during starting is in the neighborhood of 500 to 600 amps, thereby requiring considerable battery capacity.

Spring starter systems were also recommended. Hydraulic starters were characterized as being potentially troublesome at temperatures of -22^{O}F because of the increased fluid viscosity; these starters also tend to pose increased maintenance problems as well although these claims are denied by hydraulic starter manufacturers as well as one engine manufacturer.

Use of pyrotechnic cartridge starters was strongly discouraged. It was stressed that they tend to be complex, dangerous, (especially in closed boats), highly corrosive, and pose logistic and storage problems. Their high impulsive cranking also tends to damage a cold engine.

5) Starting aids injected into the intake during cranking were recommended. There appears to be a significant and satisfactory history of operation with commercially available devices such as the Turner Quick Start system.

6) The engine environment should be changed. This means either heating or sheltering the engine or heating the coolant, fuel and intake air and also possibly the lube-oil.

Other measures were proposed to enhance cold-starting. These however would require special engine designs or modifications. Included in this category were:

1) Increasing the size and mass distribution of the engine flywheel.
2) Altering the engine timing.
3) Providing Glow Plugs in the combustion chamber.

Needless to say, the engine manufacture's survey influenced considerably the methodology and aid selection for testing.

3.2 Product Survey and Selection

As previously implied, the product survey did not turn-up new and innovative methods for cold weather starting. It did, however, identify improved designs in accessories and areas for technology transfer from other industries. In this regard, some of the systems developed mainly for the trucking industry were found to be directly applicable, and were selected for the test phase of this program.

The products CASDE Corporation evaluated during Part II are discussed in the sections that follows.

3.2.1 Lubricants.

A very light weight oil having low viscosity at -22^{o}F is necessary to maintain reasonably low cranking torque and lubrication to moving parts. Low torque is essential to minimize power consumption and attain high cranking RPM. The sources contacted suggested using oil of SAE 5 weight or equivalent. Multi viscosity oils and synthetic formulations were found which reduce cranking power while also providing long life and stability.

The oil companies who responded to enquires or consented to interviews did not volunteer any technical data beyond application information in prepared brochures.

For purposes of the test and evaluation phase of this study, any 5W formulation would have served the purpose. However, a specific oil having long term stability and additives to combat rust, water intrusion, and breakdown was used; the product tested was the Mobil Oil Company's Delvac 1. This oil is claimed to be an SAE 30 synthetic oil with fluidity at low-temperature equivalent to SAE 5W. It satisfies the requirements of Mil-L-10295 B specifications for sub-zero engine oil lubrication and has long term oxidation stability, retention of alkalinity, high-temperature detergency, dispersancy, corrosion and sludge protection and permits extended oil and filter changes. As a consequence, oil heating was not necessary and its omission eliminated the possibility of "coking" about the heater coils.

3.2.2 Fuels

For service and starting at -22°F ambient temperature, diesel fuel should have particular characteristics not consistantly found in No. 1 or No. 2 fuel oil. Essential characteristics are:

1. <u>Pour Point</u>: the lowest temperature (°F) at which an oil will flow. This is a factor of significance in cold-weather start-up and operation. The pour point should be at least 10°F lower than the temperature at which an engine will be expected to start and operate. In this application, fuel requires a pour point of -32°F or less.

No. 1 and No. 2 fuels can have pour points ranging from -85°F to 5°F and -35°F to -20°F respectively. It's clear that these fuels may not always fulfill these requirements. In fact a sample of No. 2 fuel froze solidly at -22°F during Part II tests.

2. Cloud Point: the lowest temperature (^{o}F) at which a sample becomes clouded by formation of wax crystals. It is a consideration in the plugging of fuel filters by wax. The cloud point should be no less than -22^{o}F.

No. 1 and No. 2 fuels may have cloud points of -78^{o}F to -10^{o}F and -20^{o}F to 32^{o}F respectively and are not suitable for this service.

3. Water and Sediment: the volume of water and foreign matter which can be removed by centrifuging. These affect the rate of fuel filter plugging and are particularly critical at operating temperatures below freezing (32^{o}F).

4. Cetane Number: a measure of the ignition quality of diesel fuel. High Cetane numbers indicate shorter ignition lag and ignition at lower temperatures. The recommended Cetane No. for low temperature starting is between 45 and 50 with some suggestions running as high as 90.

The fuels selected for test in Part II were aviation jet fuel A-1, also known as JP-8 and No.2 diesel fuel. Jet fuel A-1 appears to have the desired attributes and although it is relatively new, it will soon be readily available around the world, more so, than perhaps artic or winter grade diesel fuel. The No.2 diesel fuel was used for comparative purposes and to evaluate the effectiveness of fuel heaters.

3.2.3 Devices to Increase Compression Ratio

The only devices found during the survey specifically designed to aid the cold-starting of diesel engines were devoted to increasing the compression ratio during the starting process and took two forms: 1) adding oil into the cylinder and 2) closing off a volume which effectively reduced the compression clearance. Devices which add oil to the cylinders can be retrofitted to existing engines; in fact, all of the Coast Guard approved engines already have such devices. The oil thus added effectively seals the rings and reduces the final cylinder volume. Both effects

elevate the cylinder temperature for fuel ignition. After starting, the oil is simply burned. The result being a smokey exhaust for a few seconds. The controlled volume device in contrast, must be designed as part of the engine.

Two such oil devices have tradenames: "Lube Cell" and "Densifier"; both are proprietary designs. The significant difference in the two systems is in the control of the oil amounts injected into each cylinder. The Lube Cell depends on pressure equalization to distribute oil portions. The Densifier directly meters oil to each cylinder. These devices are mentioned here for the sake of completeness; they were not evaluated during the test portion primarily due to the consensus that they are not sufficient for starts in the range of -22°F.

3.2.4 Air Primer Systems

One type of primer system appeared to be generally available; it is typified by the "Turner Quick-Start" system. Fluid employed by the primer system is usally di-ethyl ether. U.S. Navy experience with ether starting reported successful starts to -20°F. At much lower temperatures ether volatility is insufficient to form combustible mixtures unless heat is added. Ether vapor pressure at -22°F is 38mm Hg as compared to 442mm Hg at 68°F. Detroit Diesel Co. reports reliable starts to only -10°F; CASDE Corporation tests, however, found reliable starts at -22°F.

For reliable usage, the injector path should be length-wise along the manifold but not into the intake ports directly. Injection is by fine spray to assure vaporization and should be at a point close to or inside the air cleaner. Care should be taken not to inject an excessive amount of ether; if this happens, pre-ignition will occur with a resultant heavy knocking. Ether systems are not advised with flame type air heaters but are otherwise safe and readily adapted to remote operation without a pump of any kind. In situations where high ambient temperatures exist, there is no need to use the ether system; if is is used under these conditions,

however, the ether will have a tendency to vaporize too quickly; it should not pose any serious problems, however.

These systems employ a throw away pressureized canister and are widely used in the trucking industry and in the Whittaker survival capsule. CASDE Corporation evaluated two similar systems: the Turner Quick-Start and the KBI Diesel Start Systems.

3.2.5 Batteries

This section of the report describes various types of electrical storage batteries, their temperature versus capacity characteristics, cost, anticipated life and maintenance requirements. The results of a trade-off study leading to the battery type selections for testing are discussed below.

It should be recognized that when using lead-acid batteries, engine starting without aids is limited to ambient temperature above approximately +20^{o}F. Further complications are that starter motors normally draw 500 to 600 amperes of current. A battery system which permits starting at temperatures approaching -22^{o}F is a major objective of this study. A maintenance-free system is also desireable, particularly with the infrequent operation of engines which is typical of life boat service.

3.2.5.1 Battery Characteristics and Tradeoffs

Engines taken as models for the battery study were those of Lister and Perkins. Other Coast Guard approved engines, e.g., those of Westerbeke and Farymann, were considered sufficiently similar to enable generalized conclusions to be drawn.

Characteristics of the Lister type SR-3 and HRW-2 and Perkins types 4.108 and 4.154 engine characteristic are given in Table 3-1. These models are widely used in lifeboat applications.

TABLE 3.1 ENGINE TYPES AND CHARACTERISTICS

ENGINE MANUFACTURER AND TYPE	ENGINE DISPLACEMENT	CORRECT BATTERY CAPACITY (IN A.H.) FOR $+25^{o}C(77^{o}F)$ STARTING (See Note 1)	
Lister SR-3	3CYL.,100IN.^{3},(1.65LTR)	12 V STARTER,	17.6 A.H. Battery
		24 V. STARTER,	11.2 A.H. Battery
Lister HRW-2	2CYL.,128IN.^{3},(2.09LTR)	12 V. STARTER,	26.3 A.H. Battery
		24 V. STARTER,	11.2 A.H. Battery
Perkins 4.108	4CYL,107IN.^{3},(1.76LTR)	12 V. STARTER,	21.9 A.H. Battery
		24 V. STARTER,	11.2 A.H. Battery
Perkins 4.154	4CYL,154IN.^{3},(2.5LTRS)	12 V. STARTER,	26.3 A.H. Battery
		24 V. STARTER,	11.2 A.H. Battery

Note 1: Battery capacity shown will provide 3 each, 10 second engine cranks, at $77^{o}F(25^{o}C)$ with a reserve of 50% capacity. Time between cranks is 10 seconds each. Engine lubricant is SAE 30W. The battery assumed is a high rate, nickel-cadmium type. Data shown was supplied by NIFE inc.

Storage Battery Characteristics

The following electrochemical couples are potentially suitable for the lifeboat application:

A.	Nickel-Cadmium, (NI-CD)	Sintered Plate, both flooded and starved electrolyte, and Pocket Plate cell types (starved electrolyte cell in sealed KOH Electrolyte)
B.	Silver-Zinc, (AG-ZN)	Flooded, vented cell, KOH Electrolyte
C.	Silver-Cadmium, (AG-CD)	Flooded, vented cell, KOH Electrolvte
D.	Nickel-Zinc, (NI-ZN)	Flooded, vented cell, KOH Electrolyte
E.	Lead-Acid, (PB-Acid)	Both sealed and vented, Acid Electrolyte

A comparison of the relative performance characteristics of each type of battery listed is shown in Table 3.2.

It can be seen from Table 3-2 that sintered plate, NI-CD batteries may be expected to perform reasonably well down to -20°C, however, at -40°C all batteries are poor performers. The data (capacity) shown for -40°C is theoretical, since at that temperature all potasium-hydroxide (KOH) electrolyte concentrations are frozen, and the ion exchange properties of the electrolyte approaches zero. The acid electrolyte will freeze at higher temperature than that of the KOH electrolyte.

Table 3-3 summarizes and ranks various battery attributes. The table provides ease of comparison; the numbers assigned are largely judgemental based on interpretation of the facts gathered.

It can be seen from Table 3-3 that applications requiring high discharge rates (400-500 amperes) and low temperature operation are best served by a NI-CD sintered plate, vented cell battery; the lead acid batter is the poorest choice. For testing purposes, however, a NI-CD pocket plate battery and a lead acid battery were selected. The choice of the pocket plate over the sintered plate NI-CD battery was based strictly on availability and cost for the one-of-a-kind testing. The lead acid battery was selected to test the effectiveness of battery heaters and was not intended for testing below +20°F. Both were 24 volt batteries. The 24 volts were selected to reduce the current requirements during starting since, under high discharge rates, batteries supply current more efficiently than voltage at low temperature.

ELECTRO CHEMICAL COUPLE	NOMINAL DISCHARGE Voltage- Volts @ 25%C	BATTERY CAPACITY REMAINING WHEN DISCHARGED AT 1C Rate At: (1) 0°C	-20°C	-40°C	AMPERE-HOUR Efficiency (°/o) (2)	WATT HOUR Efficiency (°/o) (3)	CYCLIC (4) LIFE (Charge-Discharge Cycles)	TOTAL (5) LIFE (YEARS)
NI-CD (Sintered-Sealed)	1.25V	92%	76%	~20%	67-71.5	60-65	200-2000	2-10
NI-CD (Sintered-Vented)	1.25V	87%	63%	25%	71.5-83.5	62-75	300-2000	3-10
NI-CD (Pocket Vented)	1.20V	85%	57%	9%	71.5	60	500-2000	8-25
AG-ZN	1.48~1.50V	82%	41%	12%	90-95	70-75	10-100	0.5-1.5
AG-CD	1.05V	80%	—	—	90-95	~70	300-500	1-3
NI-ZN	1.60V	90%	65%	~15%	~80	~70	100-200	Unknown
PB-ACID	1.75	38%	28%	17%	83-91	68~70	500-1000	2-4

TABLE 3.2 TYPICAL BATTERY CHARACTERISTICS FOR MEDIUM RATE CELLS

Notes:
(1) Temperature performance to be expected when battery is discharged at 1C rate, i.e. a 50 A.H. Battery discharged at 50 amperes.
(2) Ampere hours of discharge current divided by ampere hours of charge current required to restore the battery to full capacity.
(3) Watt hours of discharge energy divided by watt hours of energy required to restore the battery to full capacity.
(4) Charge-discharge cycles down to a depth of discharge of 70%.
(5) Estimated life based on published battery replacement-periods in military environments.

ELECTRO-CHEMICAL COUPLE	HIGH RATE DISCHARGE PROPERTIES	LOW-TEMPERATURE PROPERTIES	INTERNAL RESISTANCE	CHARGE PROPERTIES	CHARGE RETENTION	LIFE	MECHANICAL PROPERTIES	FIGURE OF MERIT (Σ OF ALL ATTRIBUTES)
NI-CD (Sintered-Sealed)	5	5	5	4	1	4	5	29
NI-CD (Sintered-Vented)	5	4	5	5	3	4	5	31
NI-CD (Pocket Plate)	4	4	4	5	1	4	5	27
AG-ZN	5	3	5	2	4	1	4	24
AG-CD	3	4	2	3	4	3	4	23
N6 ZN	4	5	5	3	3	2	4	26
Pb-ACID	2	2	4	3	1	3	1	16

TABLE 3-3 RELATIVE RANKING OF VARIOUS ATTRIBUTES BY BATTERY TYPE

Note: 5 = Very Good
1 = Poor

3.2.5.2 Relative Cost Factors

The relative cost factors of the more prominent battery types are compared in Table 3-4. Further elaboration is contained in Section 8.

ELECTROCHEMICAL COUPLE	ACQUISITION COST	REPLACEMENT COSTS	TOTAL LIFE CYCLE COST
NI-CD (Sealed)	13	5	18
NI-CD (Sintered Vented)	8	4	12
NI-CD Pocket Plate (Vented)	10	1	11
PB-ACID	1	1	2

TABLE 3-4 RELATIVE COST FACTORS OF VARIOUS BATTERY TYPES

3.2.6 Battery Chargers

Each battery type discussed in Section 3.2.5 is capable of discharging its self through its internal resistance; this characteristic is known as "SELF DISCHARGE". Temperature has a pronounced effect on the rate of self discharge. Figure 3-1 shows a family of curves relating time, temperature, and capacity, which are typical of the self discharge of a sintered plate, vented NICAD battery of any size or capacity. If a ship were operating in tropical waters (T_{amb} = 100°F) a new, fully charged battery would self discharge to zero capacity remaining in approximately 40 days. A battery which had been in service for eleven months would discharge at an even faster rate due to the introduction of carbonate contaminents into the electrolyte.

Batteries should be charged at current rates somewhat proportional to the charge depletion. The most common unattended systems charge at essentially constant voltage simply because constant voltage control circuits are relatively simple. Problems arise at the end of the charging cycle in that battery temperature is not considered by the control and some gassing temperature rise may occur. The outcome is quite frequently long-term electrolyte depletion by electrolysis of water from the battery. An improvement in control is afforded by adding a fixed resistor in series with the battery which limits and fixes the final current rather than the diminishing battery internal impedance. The result is constant-current charging in the finishing phase which reduces the need for attention.

A recently developed technique for fast charging employs pulses of current wherein the battery is charged by bursts of current with idle periods in between. This technique does not build up a gas barrier at the plates which normally limits the chemical process of charge replenishment.

Fast charging does not seem to be a valued objective in this application, but pulse-charging may provide a better measure of control during the trickle-charge phase.

Solar charging was not considered practical for this application even though it has been used successfully in space vehicles for the following reasons. The current capability to convert solar energy to electric power by Silicon or Cadmium-Sulphide cell arrays is about 6 to 10%. After necessary environmental moisture and mechanical damage has been considered, system efficiency will be 2% or less. At sea, a solar tracking system for the array is not practical nor desireable. Consequently, an Omni-directional array would be necessary covering 360° in azimuth and 90° in elevation. A fixed layout will therefore require four to five times the theoretical cell surface. The area required will be comparable to the boat itselt.

A typical 40 Hp boat engine comes equipped with a 14 AMP generator. This is an output of approximately 0.2 KW. Current systems are costing $10,000 to $15,000 per KW.

If one limits the system task to charge maintenance and trickle-charging, the size and cost are reduced significantly. However, the reliability and output dependability would still be less than desired. When one makes a trade-off between the effectiveness and cost of solar charging and a system employing dependable and virtually ever-present ship's electrical power, there seems to be little merit in this approach at this time.

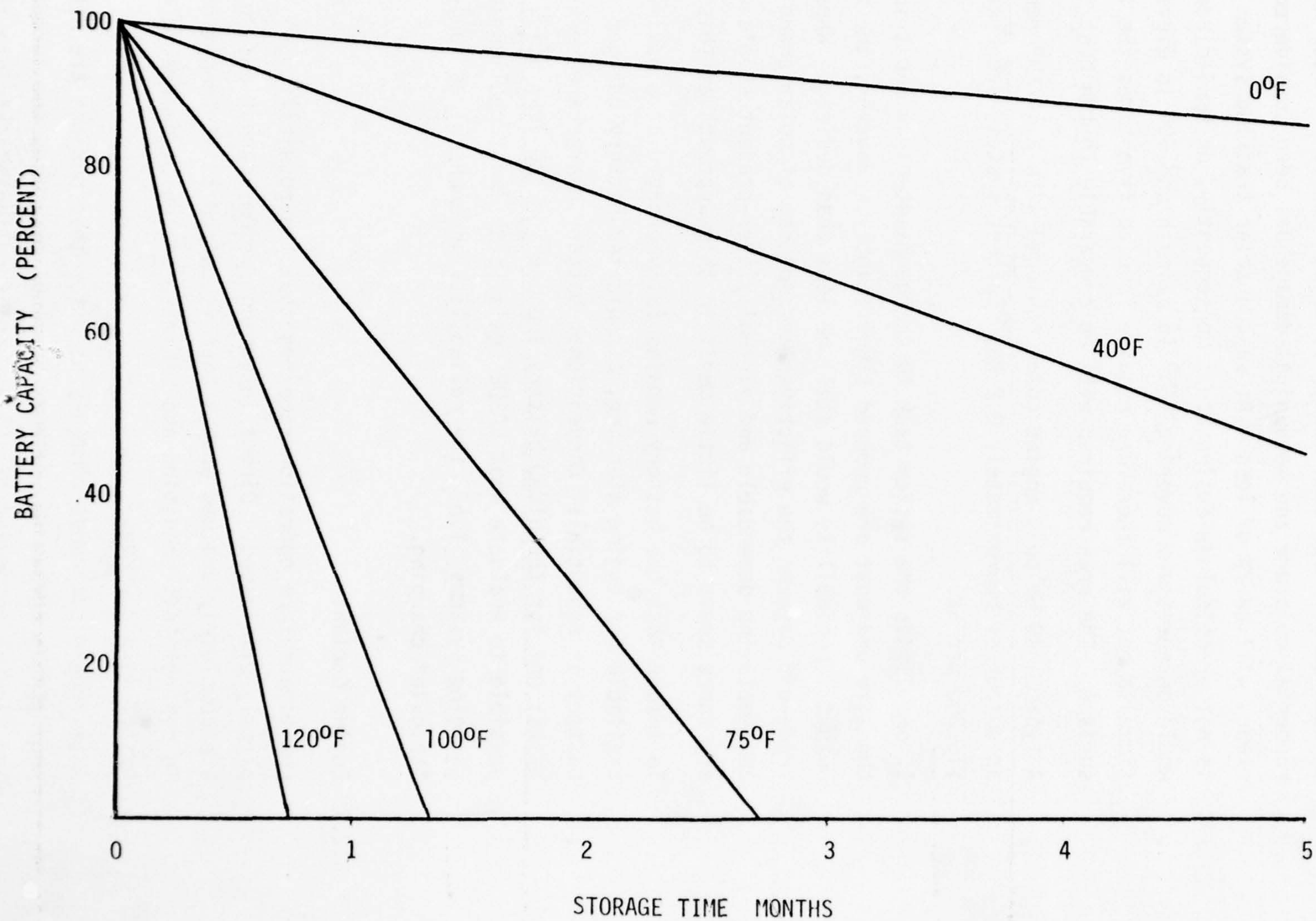
To insure that the battery remains fully charged at a maximum capacity and available for engine starting, a dedicated battery charger for each boat/battery is essential. Conventional battery chargers were used during the tests: one for the NICAD battery and one for the lead acid, since it was not possible to evaluate what CASDE feels is the most challenging problem in charging systems, i.e., the reliability and control of long-term, unattended "trickle" charging.

3.2.7 Engine Coolant

Low temperature operation requires that the possibility of freezing be completely eliminated. Direct injection systems cannot assure that engines are completely drained when a boat is raised to its position in the davits. To control this condition and minimize corrosion damage, a closed coolant system is preferred.

Anti-freeze compounds commonly used for this purpose are Ethylene Glycol and Methoxy Propanol. Methoxy Propanol minimizes the formation of sludge and varnish in engine oil in the event collant leaks into the lube-oil

FIGURE 3-1 Typical Self Discharge Characteristics of Sintered Plate NICAD Battery



system. Methoxy Propanol, however, is incompatible with various elastomers, such as BUNA "N", Polyacrylics and VITON thus causing softening, expansion and deterioration of hoses, "O" rings, and gaskets. A 50% mixture of Ethylene Glycol protects to -33°F whereas a Methoxy Propanol 63% mixture protects against freezing to -75°F.

For the purpose of laboratory tests, CASDE Corporation chose to use Ethylene Glycol since it is readily available and is compatible with hoses and gaskets as delivered with the engine.

To enhance engine reliability and reduce maintenance in the long term, consideration should be given to the specification of Methoxy Propanol compatible substances in new engines and consequent use of this coolant in the future.

3.2.8 Coolant, Lube-Oil Heaters

Coolant heaters have been consistently recommended or indicated by almost every experienced individual interviewed and by relevent references in the literature. By contrast, lube-oil heaters have not been universally recommended nor does their need appear necessary if the proper oil is used.

There are several experienced sources of engine coolant and lubricating oil heaters. One is well known to the Coast Guard, having provided heaters for lifeboats of the U.S.S. Manhattan in its epic making artic transit: that supplier is the KIM Hotstart Manufacturing Co., Inc.

3.2.9 Starters and Starter Systems

Since the starter system is a particularly critical element in the low-temperature starting problem, a comprehensive survey was conducted. Starting systems of all types were assessed and grouped as follows:

1) Air and Pyrotechnic
2) Mechanical-Spring Wound
3) Hydraulic
4) Electric

The survey for each type is discussed below.

3.2.9.1 Air and Pyrotechnic Starters

Air starters provide high power and components do not overheat with continuous cranking. The system requires a rather large air tank; ship service compressed air is necessary to replenish the air supply. Engine-driven pumps are available to keep the tank full after the boat leaves the davit. Air systems are reported as being reliably used in large trucks in all sorts of weather. Typical system components are shown in Figure 3-2.

A complication in a system of this type is the possiblity that the air valves and motors may freeze up from moisture in the air. Special measures are required to assure a dry air supply; the air tank is fitted with two smaller tanks in series which serve as moisture traps before air is admitted to the main-tank. The lower tank, called the wet tank is provided with a minimum of one-half gallon of alcohol to minimize the possibility of water freezing in the system.

Air motors are also available which employ either compressed air or dry nitrogen and a pyro-technic cartridge. These systems are reputed to give long heavy cranking power with air but only four seconds with the pyro-technic cartridge. One bottle of nitrogen gas is capable of up to a hundred normal starts. These systems are finding usage in trucks all over the world, but as previously mentioned have not found wide usage on lifeboats; the pyrotechnic cartridge has been particularly resisted. Figure 3-3 shows a cartridge starting system and Figure 3-4 typical breech components.

An air starter system provided by Ingersoll-Rand was used to test this concept.

3.2.9.2 Spring Starters

A spring-wound starter has been developed in England which employs a Bellville spring assembly and a ball-bearing lead-screw to provide cranking power. Approximately 12 turns of a manual crank fully winds

the system. The data provided did not indicate how many revolutions of the starter pinion result. Inspection of the internal mechanism however, suggested that only a few turns of the starter pinion would result. During conduct of the tests, this turned out to be a severe limitation of this type of starter in that insufficient turning of the engine flywheel limited its effectiveness at reduced temperatures. The system offers however, some attractive features; it is completely self-contained and independent of any power supply other than manual windup. It was selected for testing based upon the premise that if aids were found to be effective enough to consistantly permit quick starts, then the spring-wound starter might offer an attractive alternative to powered systems. The mechanical starter is widely used in Europe in farm, stationary plant and marine applications.

3.2.9.3 Hydraulic Starters

Hydraulic starter systems provide high cranking power but are limited in endurance by their supply systems. Like air, hydraulic systems are complex, bulky and expensive. For smaller engines they normally contain provisions for manual pumping to charge the system. Electric pumps are available and are a desireable feature since manual pumping is both laborious and quite slow. Engine-driven pumps can be used to restore pressure after starting.

Hydraulic pressure is stored in gas-charged accumulators which diminish in pressure as they are used. Current systems use two-3 gallon accumulators to fulfill the existing +20°F starting requirement. For testing purposes, two-6 gallon accumulators were used at -22°F.

Two hydraulic systems were considered for testing: the Bryce-Berger Ltd. system and American Bosch. The Bryce-Berger system has a starting pressure of 4250 psi for each accumulator. The lever force at full pressure is 45 lbs. Maintenance is said to be simple, except for the nitrogen-charged accumulator which requires a specially-trained mechanic. This system is explosion proof and adaptable to remote manual or electric control.

The starter motor consists of two piston-driven racks and one pinion which is attached to the end of the crank shaft through an engaging mechanism. It has only three moving parts. Springs return the pistons and racks after each impulse.

Attachment to an engine requires precise alignment, machine work on the engine, and heavy brackets. This system will not attach to the ring-gear port which normally accomodates electric starters.

Rotation of the hydraulic motor is not continuous. Each impulse appears to cause approximately two revolutions of the pinion. Precise output turns were not revealed. The system will produce one or three impulses per accumulator depending upon which of two accumulator models offered are used. An electric pump is available to relieve hand pumping. An engine-driven pump is also offered for recharging after the engine starts.

The American Bosch system also employs piston accumulators which charge to 3000 psi. The principal difference between this system and the Bryce-Berger design lies in the starter motor. The Bosch unit is a seven-cylinder, positive displacement motor which revolves continuously and conforms to the same form and function as an electric motor and can be simply exchanged without rework of the engine. Electric and engine-driven pumps are also offered.

In principle there is little to choose between these systems, being of virtually identical design beyond the motors. Both manufacturers claimed that their system would function at -22°F. It was not clear how much accumulator capacity would be required to fullfil the cold-start requirement since very little cold weather service date was provided by either supplier. As mentioned before, two 6 gallon accumulators were tested.

CASDE Corporation chose to evaluate the American-Bosch design because of the continuous motor feature and its ease of integration into the engine system.

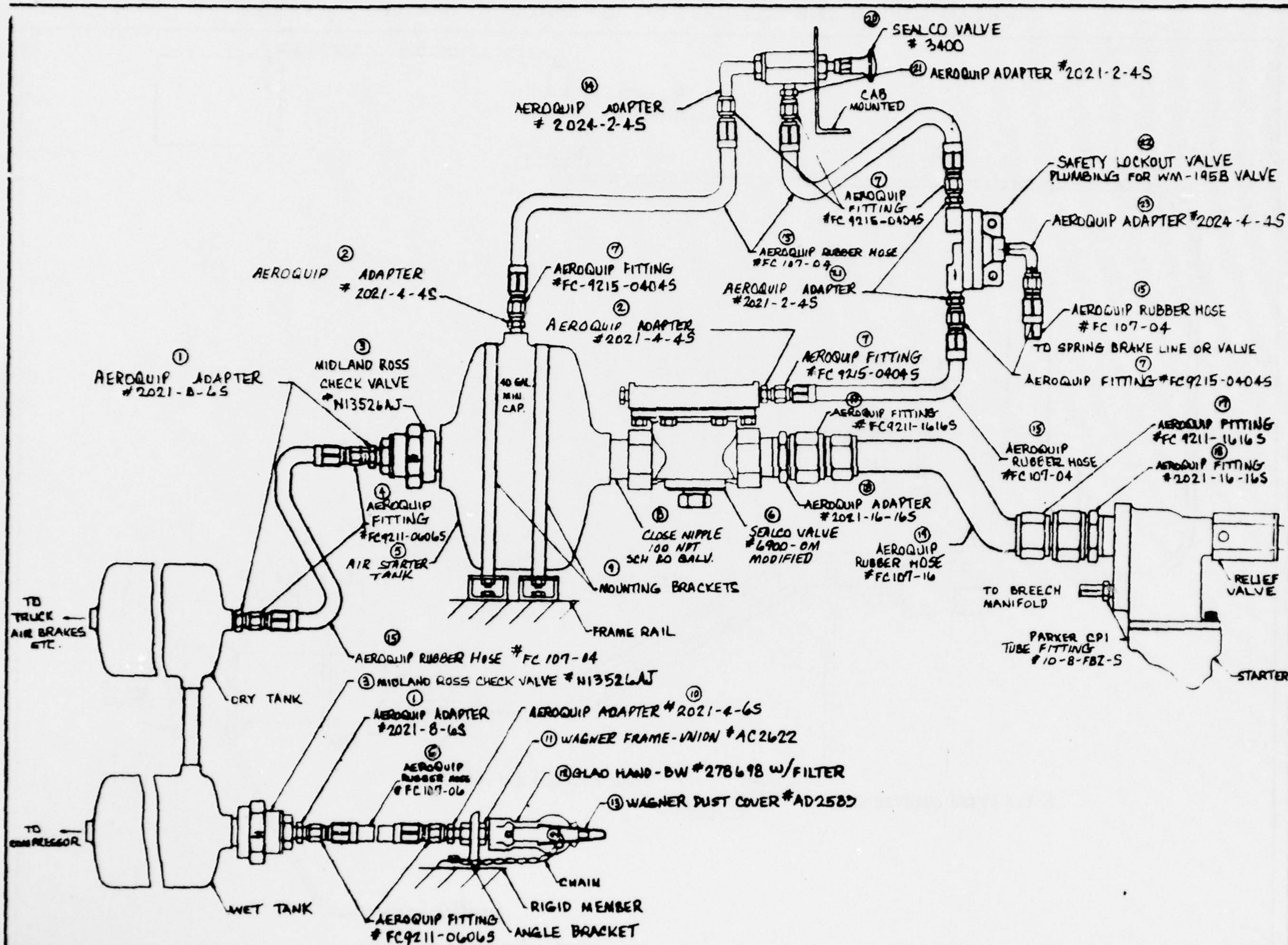


FIGURE 3-2 AIR COMPONENT PARTS ILLUSTRATION

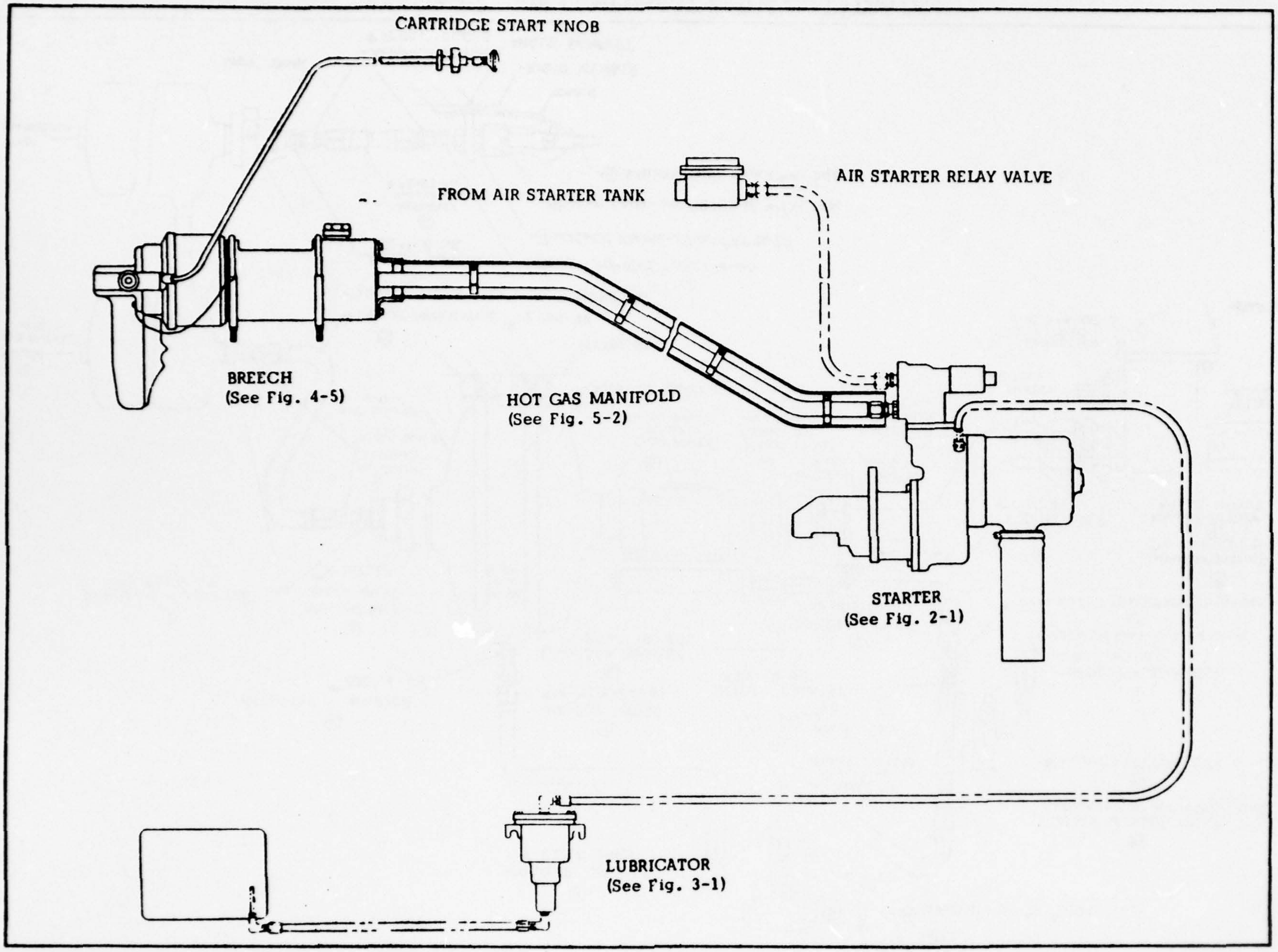


FIGURE 3-3 POW-R-QUIK DS23 AIR STARTER AND EMERGENCY OPTION

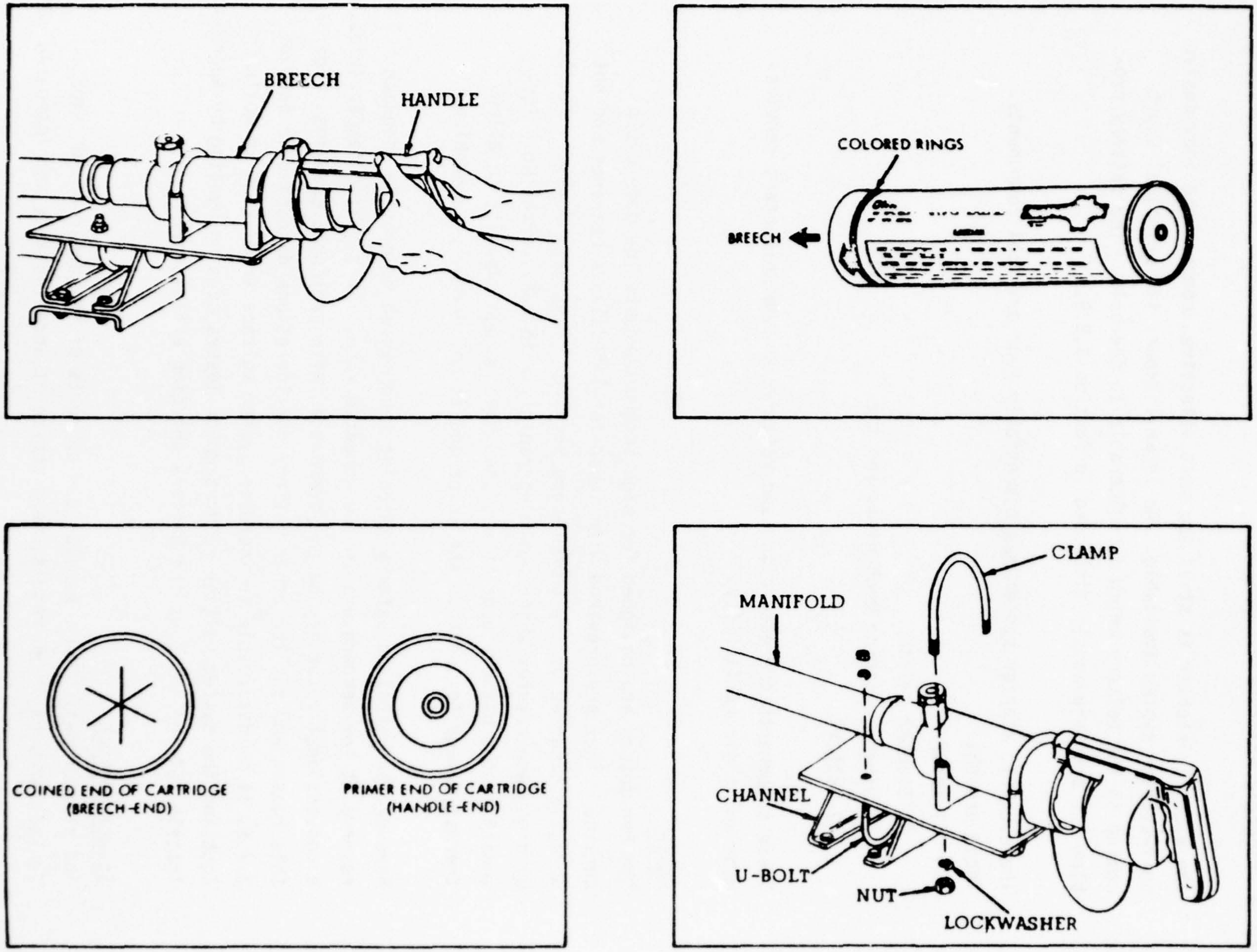

BREECH
HANDLE
COLORED RINGS
BREECH
COINED END OF CARTRIDGE
(BREECH-END)
PRIMER END OF CARTRIDGE
(HANDLE-END)
CLAMP
MANIFOLD
CHANNEL
U-BOLT
NUT
LOCKWASHER

FIGURE 3-4

3.2.9.4 Electric Starters

The electric starter is still the most effective, compact and inexpensive self-starter system available. As is well known, its principal shortcoming is the battery which is vulnerable to the cold. The battery problem has been previously discussed in Section 3.2.5.

The electric starter system has essentially four critical components. These are the:

1) motor
2) Starter switch
3) Pinion engaging mechanism, and the
4) Battery

These components are each discussed relative to the cold-start requirement and their reliability.

<u>Motor</u>
Starter motors are designed for high torque/current, low duty-cycle service. They are provided with lubed-for-life sleeve bearings and not normally hindered by low temperature service. They are, however, limited by high temperatures which build up rapidly with heavy cranking. Fortunately, the battery usually does not have enough capacity to allow thermal damage to occur to the motor and is not normally a problem.

However, an oversized battery is being recommended to provide adequate reserve at low temperature in the unheated mode. At elevated temperatures, a conventional motor may become overheated with prolonged cranking. For this reason and for the other battery considerations discussed in Section 3.2.5, it is desireable to increase system voltage from 12 to 24 volts. Doubling the system voltage reduces motor losses causing heating by approximately 75% and improves the battery charging efficiency.

<u>Starter Switch</u>
The starter switch must handle mean currents of the order of 500 amps. Contact erosion which results is a source of unreliability and increased main-

tenance. Testing for switch reliability is beyond the scope of this study. It is recommended that future directives require switches designed for heavy duty and long service. To attain long service, switches must contain durable contact materials of large self-renewing areas to extend the life under erosion. Contact surfaces must also be readily accessible for scheduled replacement.

Pinion Engaging Mechanisms

The Bendix and General Motors systems dominate the field and are used all over the world. The Bendix engaging system uses an eccentric weighted nut engaging a threaded lead screw. The pinion is driven by the nut to which it is attached. As the starter accelerates, the weighted nut drives the pinion into engagement. As the engine starts and overtakes the starter, the action reverses and the pinion withdraws. The General Motors system employs a solenoid to drive the pinion into engagement and a spring withdraws it.

These systems are very reliable, having been in use for about 60 years in one case and 40 in the other. They do require periodic inspection and cleaning. Dirt and congealed oil are sources of malfunction at low temperatures. Inspection and maintenance at periodic intervals is recommended for this component.

3.10 Glow Plugs

Glow plugs are electrical heaters inserted into the combustion chamber to provide a hot spot for combustion to start. Elements are heated to 1500°F by 5 to 6 amps of battery current. They are widely used in automotive diesel engines and have proven to be quite effective. They were not investigated further in this dtudy since it required design modifications to the engine so that they could be received.

3.11 Fuel Contamination Prevention

Fuel contamination of lifeboat engines due to moisture penetration, the build-up of corrosion products, biological growth, and the breakdown and deterioration with time and environment is especially severe not only for

fuel but also for lubricants and coolants. The survey did not reveal factual findings in regard to dispersants and other additives despite the feeling that a wealth of information exists. Discussions with the R&D departments of major oil companies were non-productive because of their reluctance to reveal their findings. Testing to determine the long-term effects discussed here were beyond the scope of this project.

4. Components Selected for Testing

The engines, starting aids, lubricants and associated systems which CASDE Corporation selected for evaluation during the testing phase of this study are listed below.

4.1 Diesel Engines

1. Lister engine, model HRW2M: two cylinders, water cooled, vertical, four stroke, continuous rating of 29.5 b.h.p. at 2200 rpm.
2. Farymann engine, model R30M: two cylinders, water cooled, V-configuration, four cycle, continuous rating of 24 hp SAE at 2500 rpm.

4.2 Lubricant

1. Mobil Delvac 1: Synthetic, SAE 5W-30, pour point: below -65°F.

4.3 Fuel

1. Aviation Jet Fuel A-1 (JP-8): Kerosene distilate (considered Arctic grade fuel).
2. No. 2 diesel fuel.

4.4 Heaters

1. KIM Hotstart: 750 watt-110 volt electrical jacket heater.
2. Fuel system electrical heater bands and flex strips applied as described in Section 7.5.
3. Electric battery pad: 75 watts in insulated box
4. Electric intake air heater: 1500 watts.

4.5 Air Primer Systems

1. Turner Quick Start system: ether fluid type.
2. KBI Diesel Start system: ether fluid type.

4.6 Batteries, Chargers

1. Nife Nickel Cadmium battery: 24 volts, pocket plate, vented, approximately 22 AH.
2. Delco lead acid battery: 24 volts, vented, approximately 50 AH.
3. Nife battery chargers: trickle-float, solid state.

4.7 Starting Systems

1. 24 volt electric
2. CAV spring starter: maximum stored torque 70 ft lb.
3 American Bosch hydraulic system: 2-6 gal accumulators, 3000psi working pressure, hydraulic motor, MIL-H-5606 hydraulic oil.
4. Ingersoll-Rand air starting system: 60 gallon storage tank, 120psi pressure, approximately 4hp starter.

4.8 Other Aids

1. Manual decompression system.
2. Automatic decompression system.

5. Test Facilities and Set-Up

The engines were tested in the CASDE cold chamber, shown in Figures 5-1 and 5-2, which had two separate and independent refrigeration systems. Cooling occurred by circulating cold air around the engine and systems. Separate controls and thermostats were provided for each refrigeration system; the control panel is shown in Figure 5.3. The total cooling capacity of the plant was approximately 20,000 Btu's per hour at -22°F with an outside ambient temperature of 80°F. The cold chamber consequently was able to maintain a temperature of -24°F with 2000 watts of electrical load inside the chamber. One of the refrigeration systems was provided with an auxiliary loop consisting of a 0.25" hand expansion valve and small heat exchanger inside the chamber to cool engine circulating water during prolonged engine runs. Only the Lister engine circulating water was connected through this heat exchanger since this was the engine selected for the longer runs; the Farymann engine was only run for short periods of time (less than 15 minutes).

The engines were mounted on carts with large (4" diameter) casters which allowed convenient movement by one man. A three gallon fuel tank was mounted at the forward end of each cart. The fuel line was positioned at the bottom of the fuel tank. The Farymann diesel engine was modified for closed-loop fresh water cooling and provided with a three gallon circulating water tank to duplicate sea-water injection. All coolant and circulating water was mixed with 44% Ethylene Glycol anti-freeze.

A table was also provided on each cart for convenience in mounting controls and air primer systems. The table for the Farymann engine for example supported the fuel tank, the throttle control, and the electrical control for the Turner Quick Start system. Figure 5-4 shows the Lister engine mounted on its cart and Figure 5-5 the Farymann engine.

FIGURE 5-1 CASDE Cold Chamber

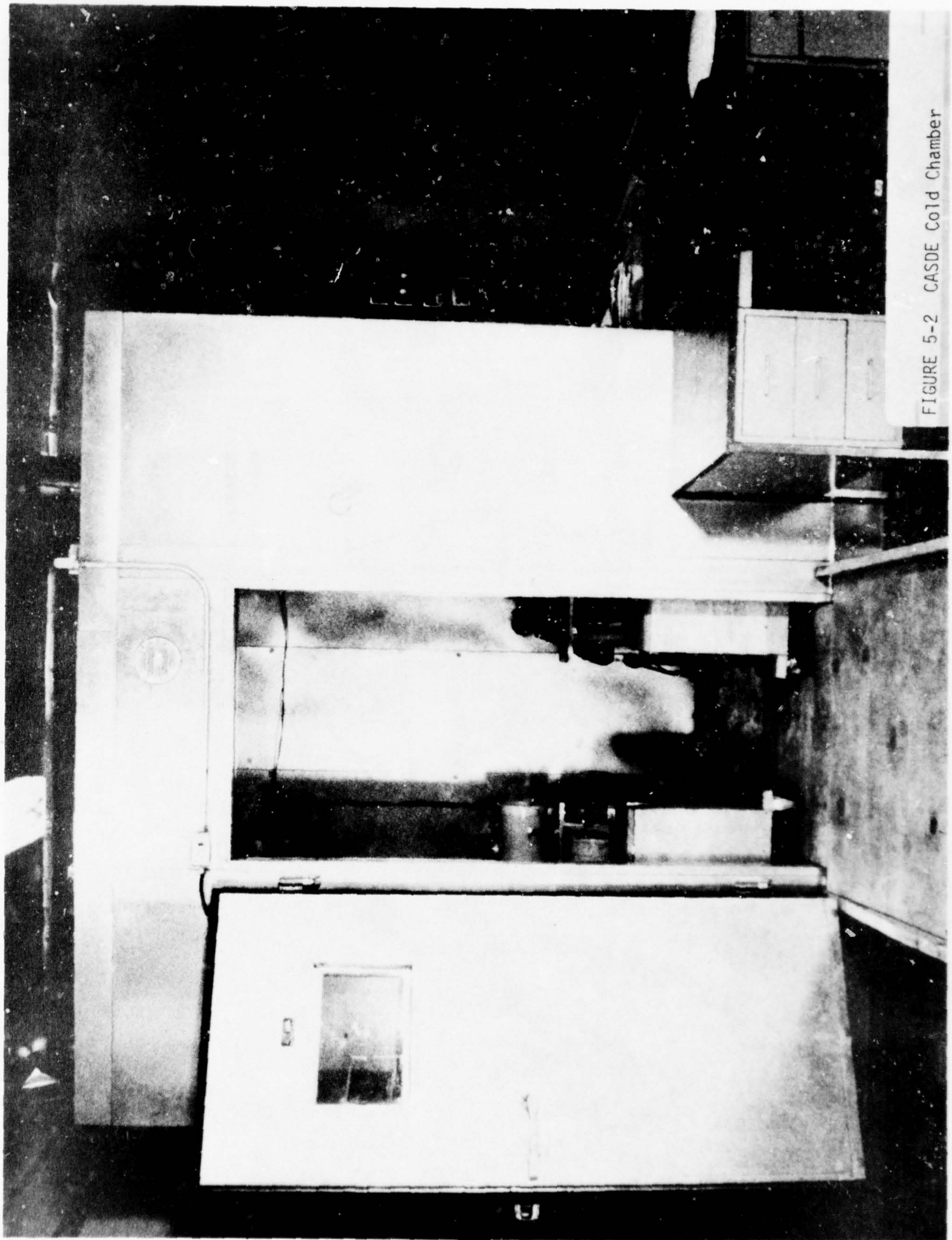


FIGURE 5-2 CASDE Cold Chamber

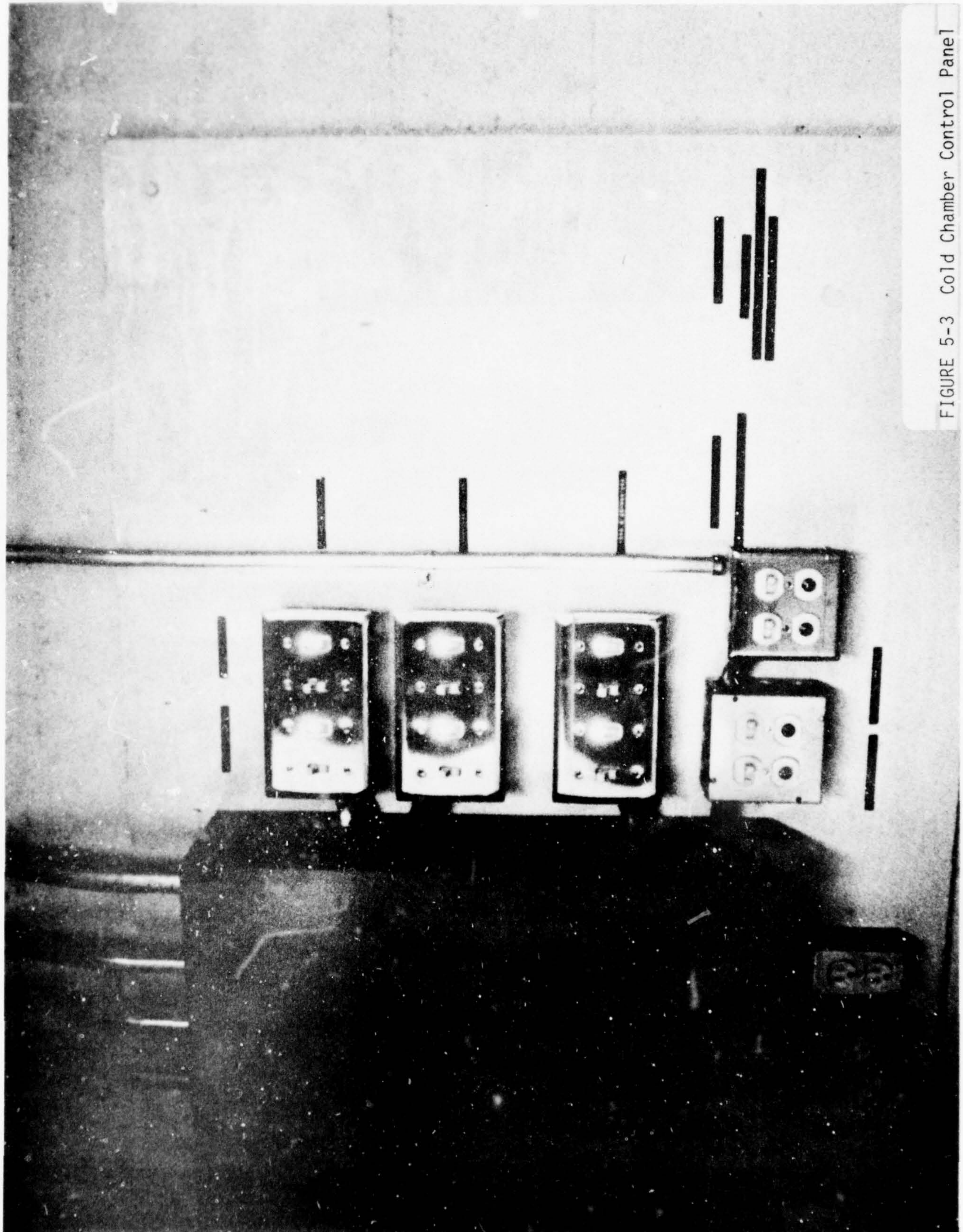


FIGURE 5-3 Cold Chamber Control Panel

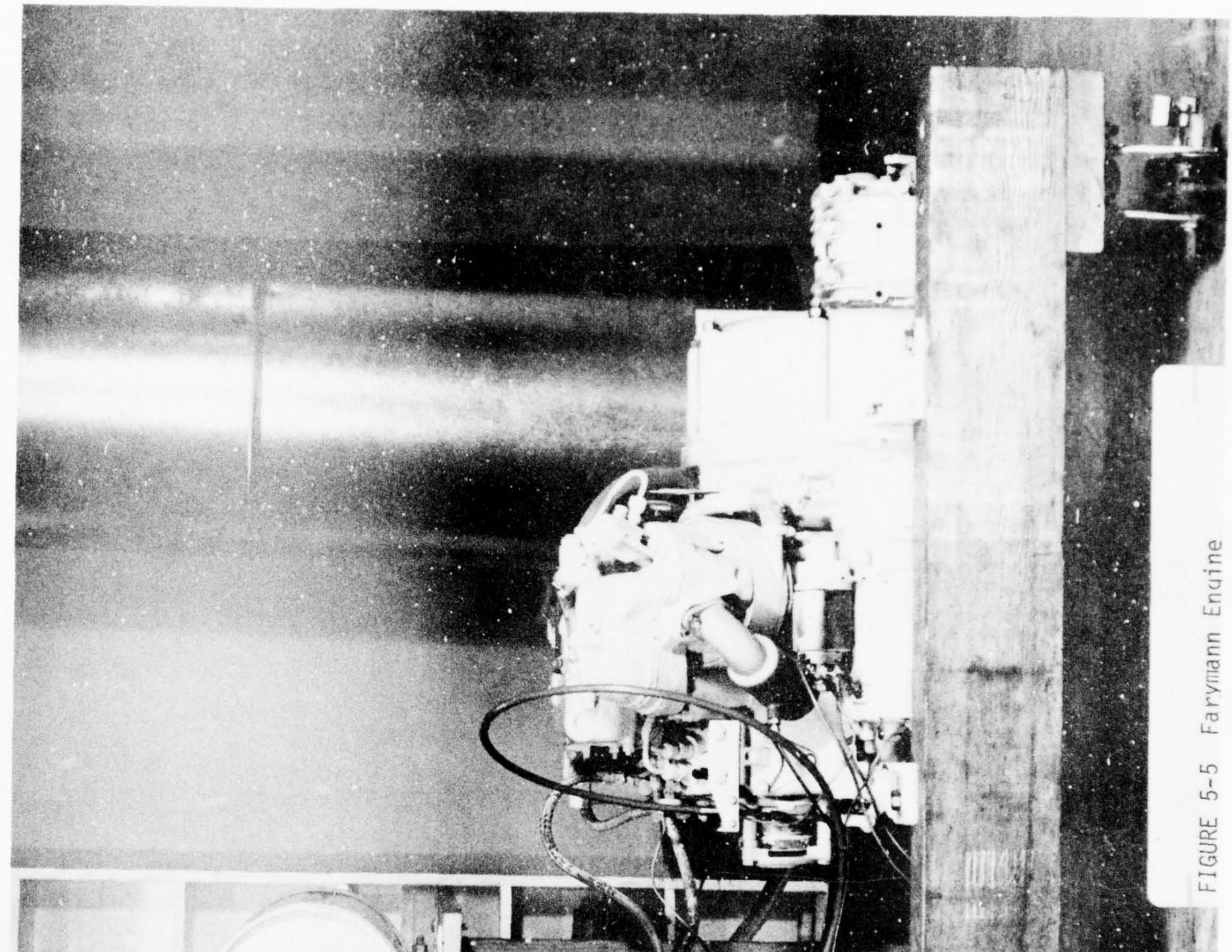


FIGURE 5-5 Farymann Engine

The engines were set-up and checked out outside the cold chamber. When ready for test the engines were moved up a 6" ramp into the chamber. This is illustrated in Figure 5-6. Inside the chamber the cart casters were secured in place by L-shaped wooden blocks fastened to the chamber floor. The engine exhaust lines were run horizontally out through the back wall of the chamber to the facility ventilation system. A muffler was provided for the Lister engine; none was required for the Farymann engine. Figure 5-7 shows the outside back wall of the chamber, the exhaust system described, and the two refrigeration systems used. Figure 5-8 shows the Lister engine positioned in place inside the chamber and Figure 5-9 shows the Farymann engine. Many of the tests were conducted with both engines positioned inside the chamber at the same time.

5.1 Instrumentation

Thermocouples were mounted to sense key engine and starting system parameters. Grounded junction thermocouples were selected with a sheath O.D. of 0.063 and 304 stainless steel sheath material; a Fluke digital thermometer (Model 2176A), matched to the "T" thermocouple calibration was used to provide temperature readings. Accuracy of the system was ± 3°F.

Test Points were as follows for the Lister engine:

1. Oil temperature, measured in the crank case through the dip-stick receptacle.
2. Engine block temperature, measured in a drilled hole approximately 3/4" deep into the engine side.
3. Engine coolant temperature, measured near the engine thermostat assembly at the coolant pump inlet.
4. Fuel temperature, measured in the tank.
5. Battery temperature, measured in the electrolyte at the centermost cell.
6. Engine inlet air temperature, measured inside the intake manifold.
7. Chamber air temperature .

Readings were recorded outside the test cell.

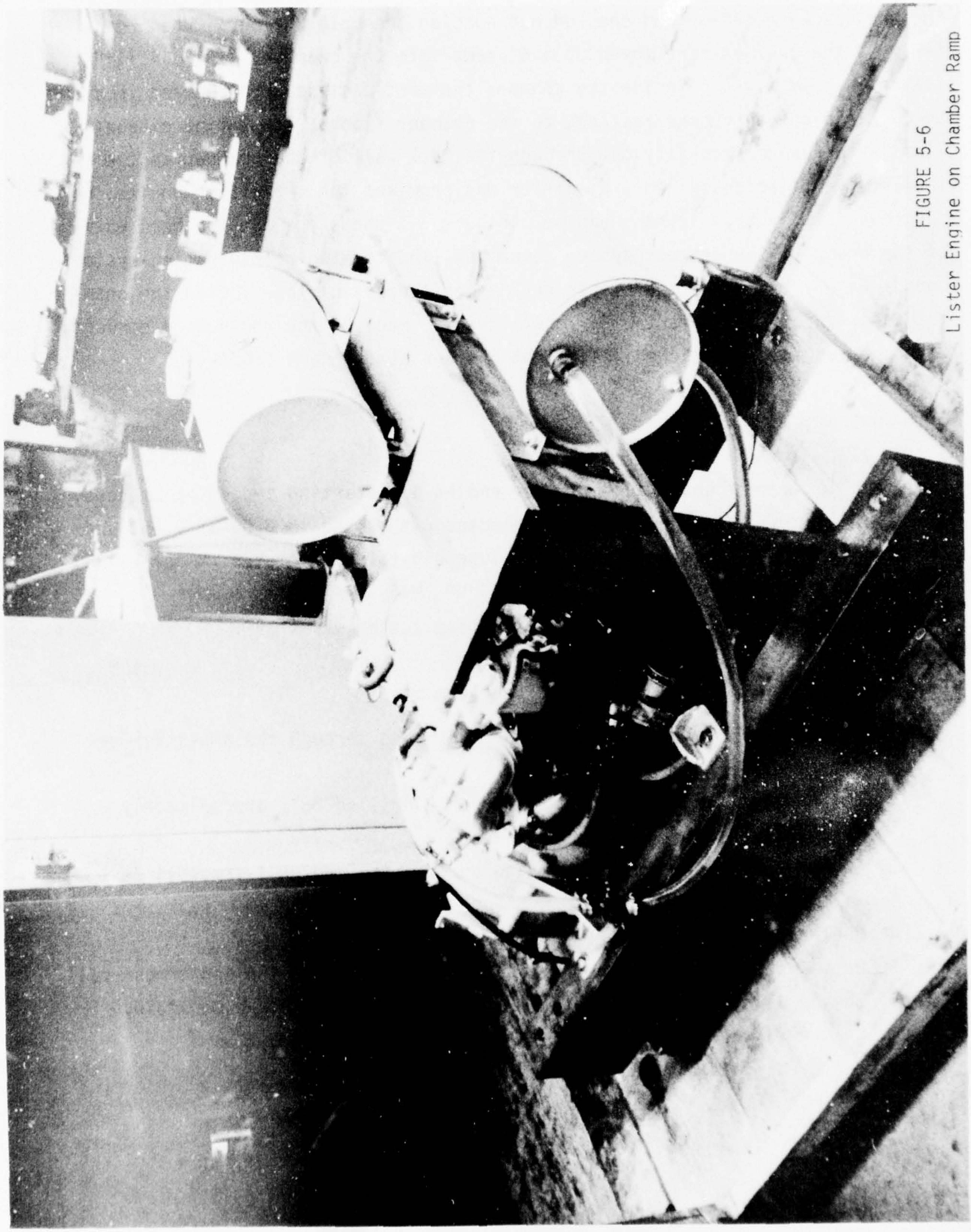


FIGURE 5-6
Lister Engine on Chamber Ramp

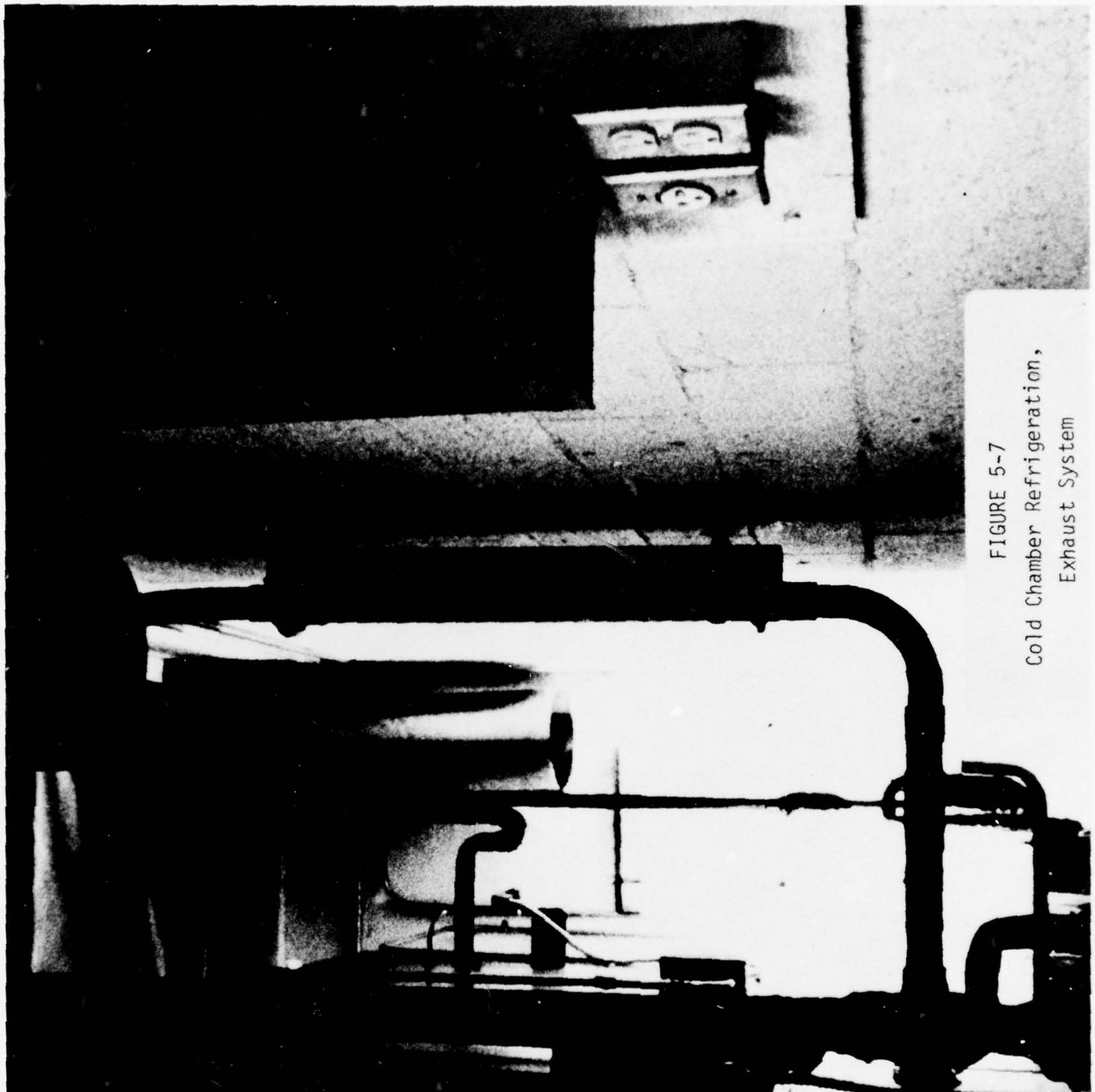


FIGURE 5-7
Cold Chamber Refrigeration,
Exhaust System

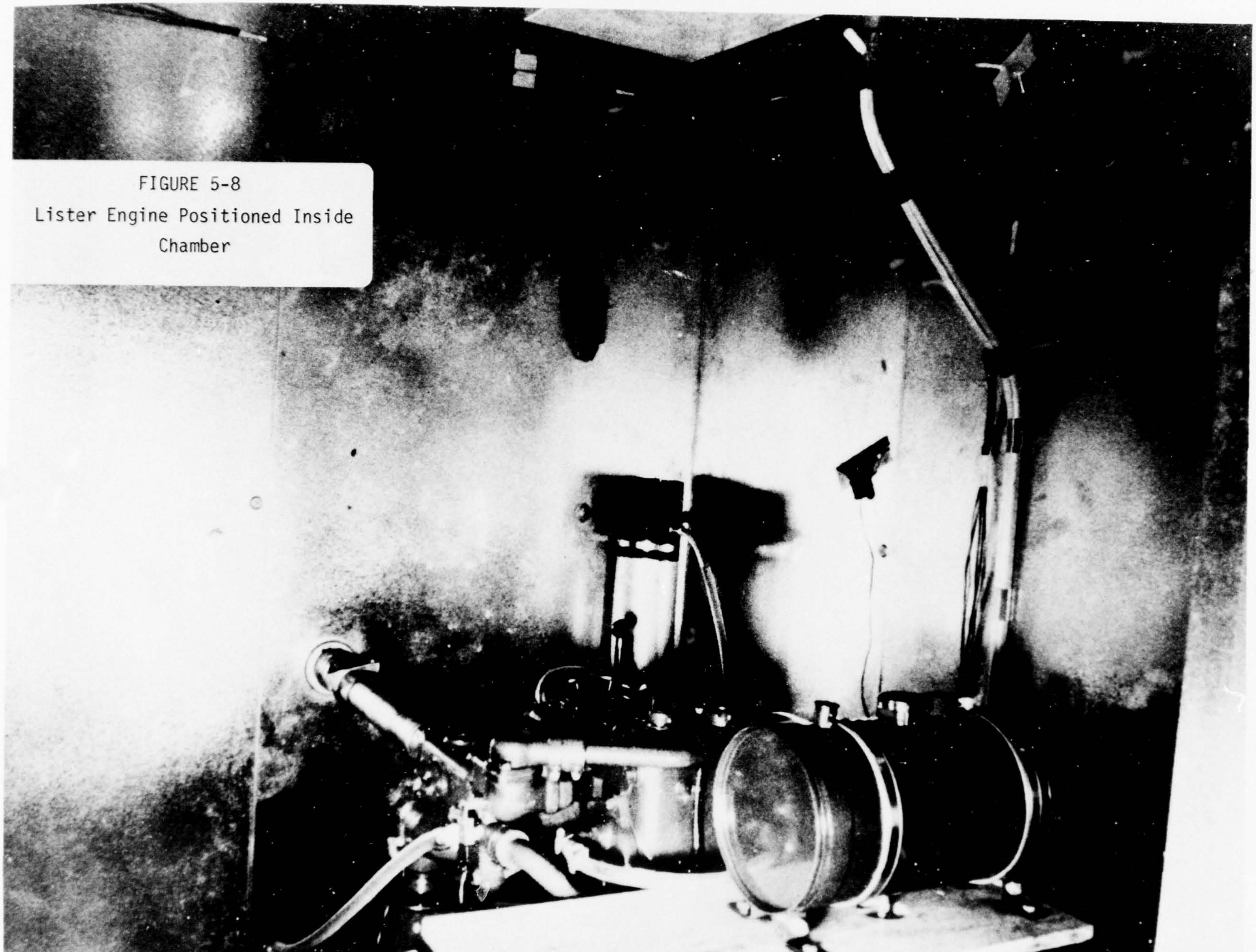


FIGURE 5-8
Lister Engine Positioned Inside Chamber

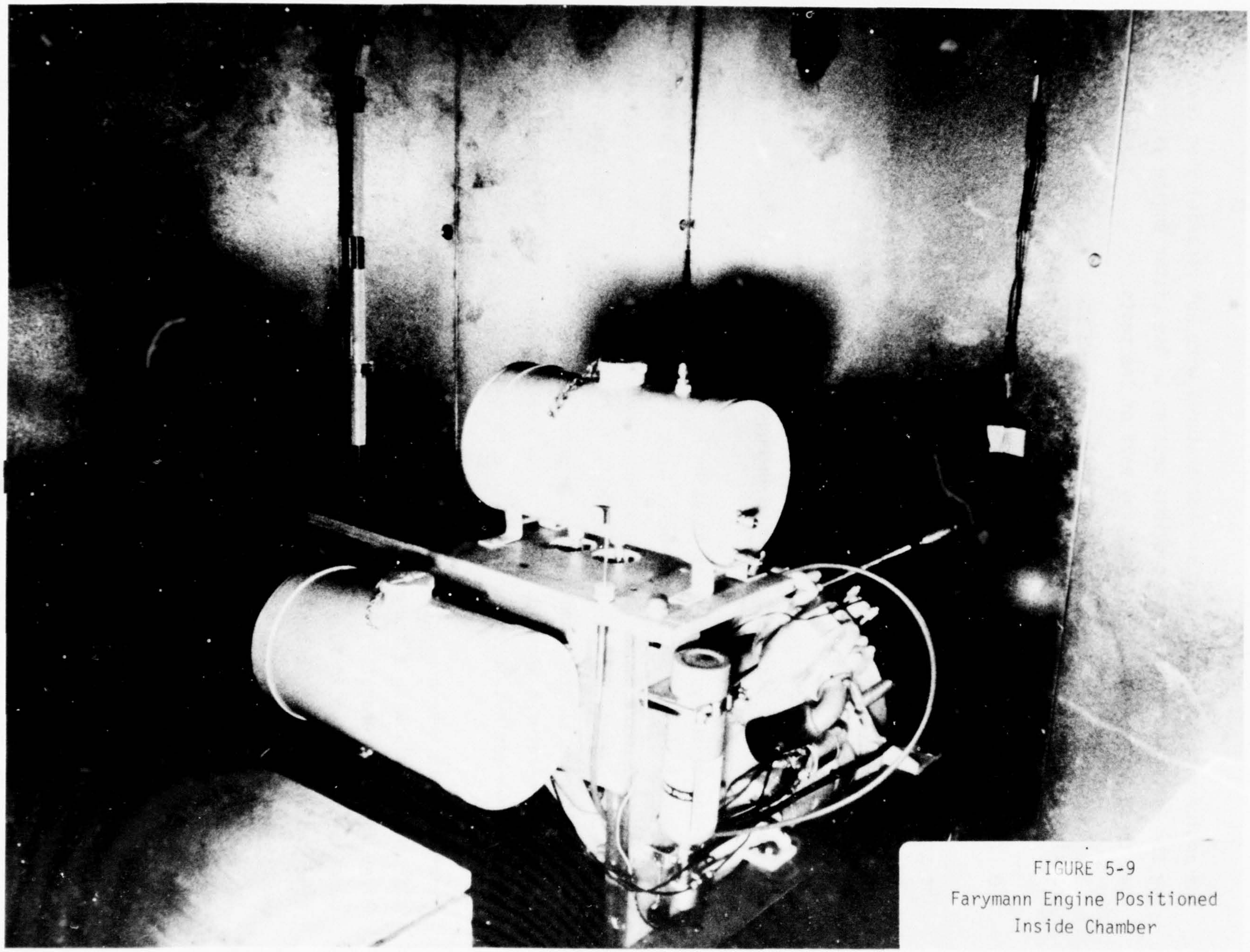


FIGURE 5-9
Farymann Engine Positioned
Inside Chamber

The engine block and the inlet air temperatures were not recorded when testing the Farymann engine since previous testing on the Lister engine showed that these parameters did not pace any part of the tests.

Cranking time was determined by a handheld stopwatch.

6.0 Test Procedure

The starting aids and heating systems selected for testing, see Section 4, were installed on the engine carts such that they could be actuated when required by a particular test. The starters and starting systems were changed for each test configuration. When making fuel changes, the fuel tank was drained and refilled with new fuel; the engine was then run for a sufficient period to ensure that old fuel impounded in engine components was fully consumed.

The refrigeration system was set-up using one or two condensing units depending upon the heating load in the chamber. Test conditions were deemed achieved when all test point temperatures had been reduced to within approximately 2°F of the test objective. Cold-soaking periods of 15 to 20 hours were not unusual. In general, test conditions were paced by engine oil and battery electrolyte temperatures when not electrically heated. In tests requiring engine and battery heating, test conditions were paced by fuel temperature.

Starting tests were conducted by entering the chamber, preparing the engine for starting and allowing a few minutes for the chamber-air temperature to restabilize. Engine preparations consisted of manually actuating the fuel transfer pump to ensure a solid fuel flow to the injector pumps, setting the engine throttle and excess fuel control in accordance with operating instructions for cold starts and setting-up the ether injection system.

Engine starts were made by simultaneously actuating the starter and ether systems. Cranking time-to-start was determined by a stop watch.

Test records consisted of temperature readings, test configuration, and time-to-start. Samples of the test records are shown in Appendix A.

It is important to note that even though the tests were run with two specific Coast Guard approved engines, i.e., the Lister HRW2M and the Farymann R30M, the emphasis was placed on examining cold starting methods and components and not on qualifying the specific engines for reduced temperature operation. The conclusions drawn from this study should generally be applicable to diesel engines of the same sizes and types.

6.1 Test Criteria

Each test sequence began with the test configuration stabilized at the test temperature. Sufficient time was allowed for proper cold soaking between each test; temperature measurements of the cold chamber space, engine block, engine coolant, and engine lubricant were used to assess the proper steady state temperature.

Each test provided for testing at higher temperatures to determine the range of applicability of the tested configuration, e.g., if proper starting was not obtained at -22^{o}F by a given configuration, the testing continued at progressively higher temperatures until proper starting was obtained.

Tested configurations were ranked according to the temperature range in which acceptable starting was obtained. The criterion for "acceptable starting" was as follows:

1. the engine started within thirty (30) seconds in the temperature range from -22^{o}F to +20^{o}F, or
2. the engine started within twenty (20) seconds at temperatures of +20^{o}F and above.

"Acceptable starting" was demonstrated on two successive occasions with proper cold-soaking between start attempts.

6.2 Test Configurations

Table 6-1 shows the test sequence followed, the test configurations, the particular item under study and the expected outcome. Testing for the Farymann engine concentrated on evaluating the effectiveness of the automatic decompress-

ion system and on selected tests needed to reinforce important conclusions. The numeral following the letter designation in the test sequence column denotes the engine used.

The sequence of tests were designed to identify the most reliable:

1. starting aid system,
2. battery, and the
3. most reliable starting system

in that order. The best of each were then used in subsequent tests to evaluate the effects of:

1. fuel,
2. battery heating,
3. coolant heating,
4. fuel heating,
5. automatic decompression
6. combinations of each.

TABLE 6-1

Test Sequence	Test Configuration	Items Being Investigated	Expected Outcome
A1	Engine #1[1], Delvac I, Arctic[2], No Heaters, Air Primer, 24V Elect Starter, NICAD[3]	Turner Quick Start and KBI Diesel Start System	More effective Air primer
B1	Engine #1, Delvac 1, Arctic, No Heaters, Air Primer, 24V Elect Start, Pb Acid Battery	Lead Acid Battery	More effective Battery
C1	Engine #1, Delvac 1, Arctic, No Heaters, Starters, Air Primer, "Best" Battery when required	Electric, Hydraulic, Air, Spring Starters	"Best" Starter System
D1	Engine #1, Delvac 1, Arctic, Air Heater only, No Air Primer, Electric Starter	Air Heater	Effect of air heating
E1	Engine #1, Delvac 1, Arctic, Air Heater, Air Primer, Electric Starter System	Air Heater in conjunction with air priming	Effectiveness and safety of Air Heater
F1	Engine #1, Delvac 1, Arctic, Battery Heater, Air Primer, 24V Elect Starter, Both Batteries	Battery Heater	Effect of Battery Heater
G1	Engine #1, Delvac 1, Coolant Heater, Air Primer, Electric Starter System	Coolant Heater	Effect of Coolant Heater
H1	Engine #1, Delvac 1, Arctic, Coolant Heater, Battery Heater, Air Primer, 24V Elect Starter, Either Battery	Coolant Heater in conjunction with Battery Heater	Effect of Coolant and Battery Heater Combination
J1	Engine #1, Delvac 1, No.2 Diesel Fuel, Fuel Heater, Air Primer, Electric Starter System	Fuel Heater	Effect of Fuel Heater
K1	Engine #1, Delvac 1, No2 Diesel Fuel, Coolant Heater, Fuel Heater, Air Primer, Electric Starter System	Fuel Heater in conjunction with coolant heater	Effect of Fuel Heater

Test Sequence	Test Configuration	Items Being Investigated	Expected Outcome
A2	Engine #2, Delvac 1, Arctic, No Heaters, Air Primer, 24V Elect Starter	NICAD Battery System with air priming	Verification of Conclusions Previously Drawn
B2	Engine #2, Delvac 1, Arctic, Battery Heater, No Air Primer, Electric Starter System	Electric Starter System with Battery Heater	Verification of Previous Conclusions
C2	Engine #2, Delvac 1, Arctic, Battery Heater, Air Primer, Electric Starter System	Air Primer	Air Primer Effectiveness
D2	Engine #2, AD(4), Delvac 1, Arctic, Battery Heater, Air Primer, Electric Starter System	Auto Decompression	Effect of Automatic Decompression System
E2	Engine #2, AD, Delvac 1, Arctic, Coolant and Battery Heaters, Air Primer, Electric Starter System	Coolant Heater	Verification of Previous Conclusions

Notes: 1) Engine #1: Lister HRW2M; Engine #2: Farymann R30M
2) Arctic: Arctic grade fuel: Jet A-1 (JP8)
3) NICAD: Nickel Cadmium Battery, Pocket Plate
4) AD: Automatic Decompression System

7. Test Results

The results discussed below are based on the test configurations discussed in Section 6-2 and presented in Table 6-1.

7.1 Starting Aids

Two starting-aid systems were tested: the Turner Quick Start and the KBI Diesel Start systems: both used an ether fluid type injection. One, however was electrically operated and employed a solenoid to actuate a metering piston which pressurized the injector at the intake manifold (the KBI system); the system requires depression of a "start" button; it is not automatic when cranking commences. Power was taken from the engine battery at 24 volts.

The other system employed a push-pull cable for manual actuation (Turner Quick Start system). There was little to choose between systems and manufacturers. Both systems functioned equally well. The electrically operated system, could, with some thought, be incorporated into the engine start sequence without an extra step. Note, however, that either system could be electrically operated. The two systems are shown mounted side-by-side for comparative evaluation on the Lister engine cart. See Figure 7-1.

A number of starts, in the normal sequence of events, were first tried without the ether fluid injection. In most cases starting without the ether fluid was not immediately seen. In some dedicated tests starts even after prolonged cranking were not possible without ether. Ether invariably aided starting and in many cases made the difference between a successful start and failure to run.

In tests employing coolant heating, starts were possible without ether. However, starting was definitely quicker when ether was used.

The selection of electrical over manual actuation is a matter of installation convenience and the proximity of the engine control panel to the engine; power usage by the electrical system was found to be quite small and did not influence battery capacity. The most critical feature was felt to be a proper selection and orientation of the injector and ether spray pattern.

Improper patterns or spray impingement on intake manifold surfaces reduced the likelihood of a quick start. A second "shot" frequently produced heavy

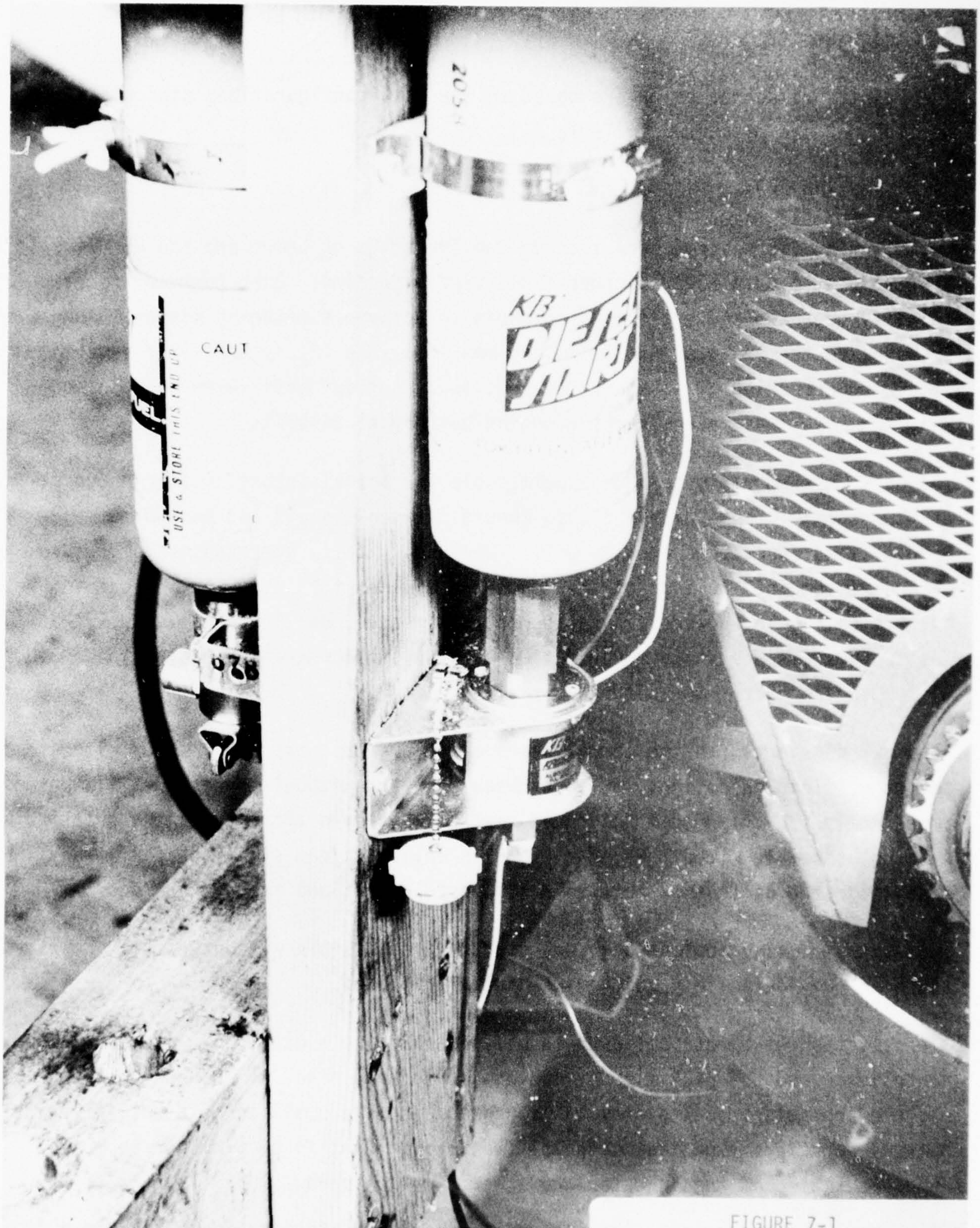


FIGURE 7-1
Turner Quick Start and KBI Diesel
Start Systems

engine knocking for 10 to 2C seconds after starting. Excessive ether was seen to settle in the bottom of the intake filter assembly as liquid. It is believed that ether continued to evaporate for some time after starting causing pre-ignition and knocking until depleted.

7.2 Batteries

The two battery types tested: the Nickel Cadminum pocket plate and the Lead Acid type, suffered electrolyte ice crystal formation at temperatures around -22^{o}F and consequently resulted in battery failure as power sources. Figure 7-2 shows a side by side comparison of the two battery types tested. The NiCAD batteries were particularly disappointing in this regard because ice crystal formation, was unexpected. Discussions with the battery manufacturer suggested the possibility of an improper electrolyte concentration. After the manufacturer replaced the electrolyte with one having a specific gravity of 1.28 and a design freeze-point of -30^{o}F, tests were resumed with a modest improvement noted; ice crystals formed in the NiCad batteries electrolyte at about -15^{o}F.

With the 1.28 specific gravity electrolyte, the NiCad battery had an improved but limited cranking power up to 0^{o}F but not enough to provide consistent engine starts. It should be stated, however, that the NiCad battery was undersized (about 25AH) by a factor of two for operation below +20^{o}F. Had the electrolyte not presented the freezing problem mentioned, the battery capacity would indeed have been doubled for purposes of the tests even though the cost and size of the battery in a practical lifeboat application would have been considered inordinate.

It should be noted that other types of NiCad batteries, e.g., those used in the aviation field of a sintered plate construction, were not evaluated because they were found to be much too expensive for the intended application (See Table 3-4).

The lead acid battery electrolyte also froze at the reduced temperatures tested as expected. Both battery types were then enclosed in insulated boxes, as pre-

viously described, and provided with a 75 watt electrical heater; this is shown in Figure 7-3. Thereafter, with the electrolyte temperatures maintained between 75 and 80^{o}F, both battery types performed well throughout the remaining tests. This development offset the expected advantage of the NiCAD battery over the lead-acid cell battery relative to their low temperature performance.

With the battery electrolyte temperature at or above +20^{o}F both battery types functioned well when fully charged. If the batteries are sized for operation at +20^{o}F and it is assumed that battery heaters are used below this temperature to maintain the electrolyte around 75^{o}F, then the cost differential shown in Table 3-4 can be reduced by a factor of two, i.e., the life cycle cost of the NiCAD pocket plate battery would be about three times as much as the lead-acid battery.

7.3 Starter Systems

7.3.1 Mechanical-Spring Wound

Installation of the CAV starter was very simple; since it was completely self contained, no interface other than the gear mesh was necessary. Manual wind-up was not difficult nor laborious, requiring only twelve turns on a removable crank. Figure 7-4 shows this particular starter and the removable crank.

The CAV starter performed well at room temperatures (60^{o} to 80^{o}F), It was particularly quiet and did not emit any noticeable gear noise typical of starters in general.

As expected from an inspection of the mechanism design, the device could not spin the Lister engine more than approximately two turns of the flywheel. Manufacturers data or information on this limitation was not available before the tests.

This limited spin capability was to prove its undoing at low temperatures. Starts at -22^{o}F were not possible with or without ether injection. Starts were, however, obtained repeatedly with engine coolant heating as they were with all starters tested.

FIGURE 7-2

Nickel Cadmium and Lead Acid (Uppermost in figure) Batteries

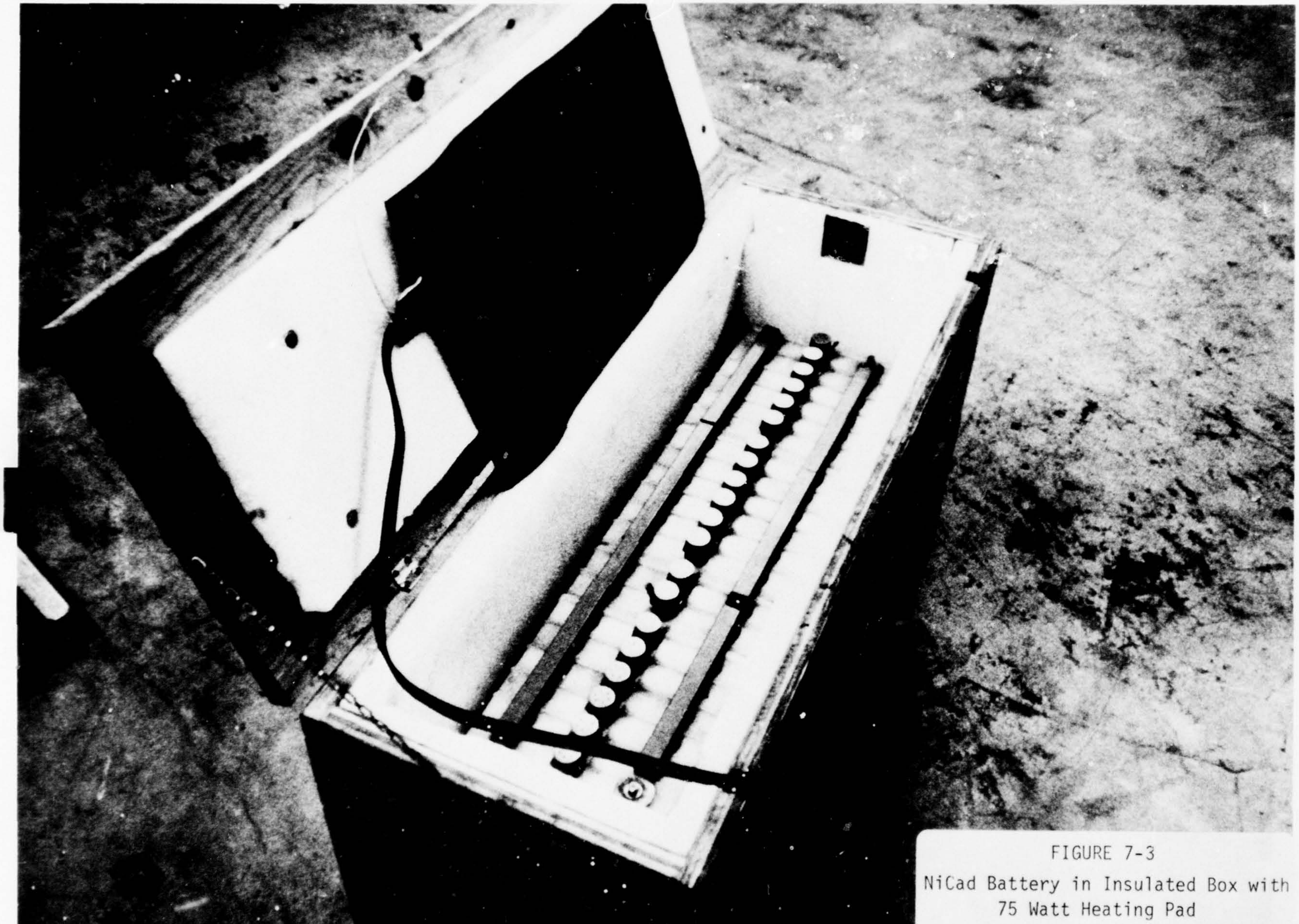


FIGURE 7-3
NiCad Battery in Insulated Box with
75 Watt Heating Pad

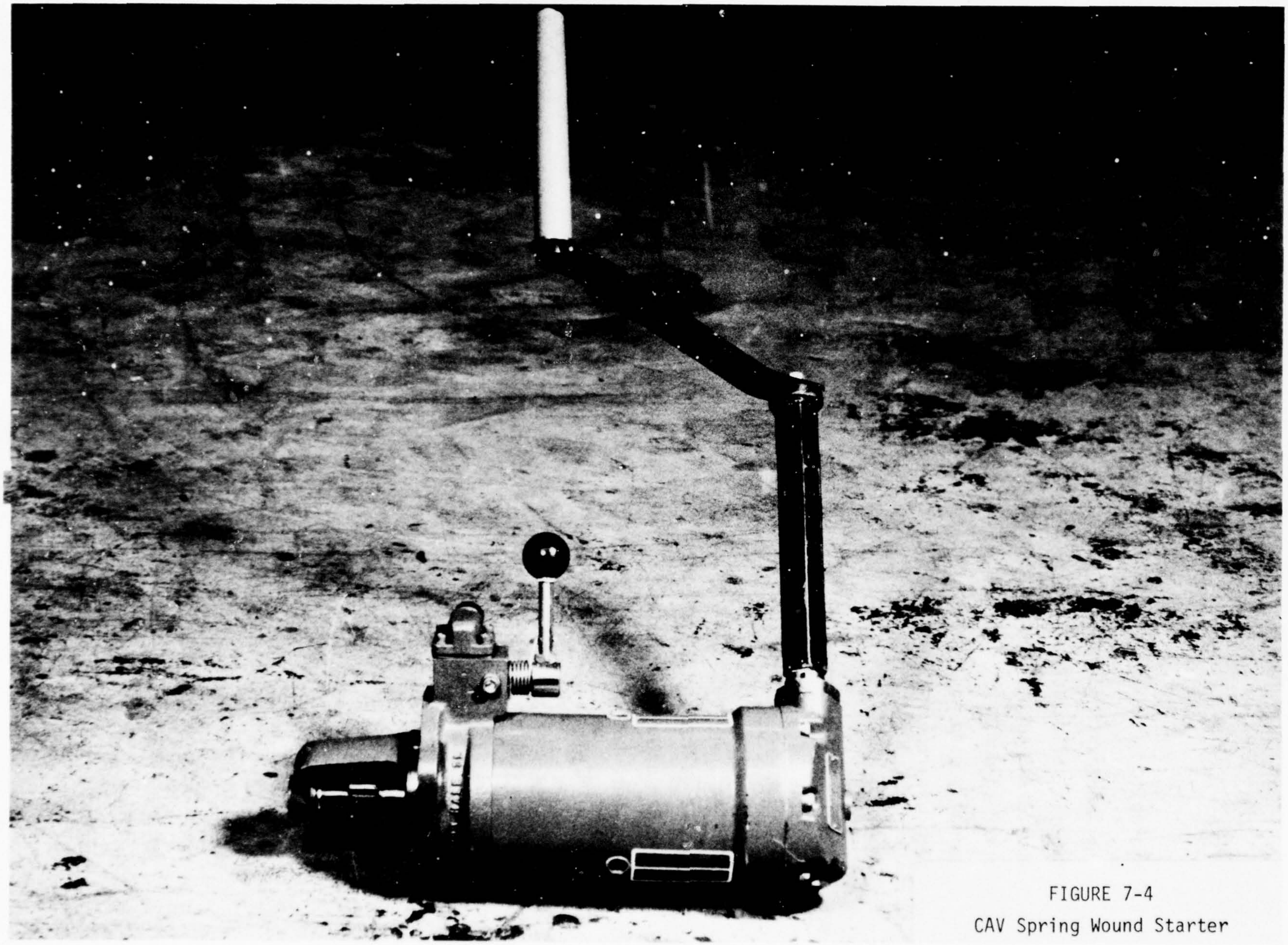


FIGURE 7-4
CAV Spring Wound Starter

7.3.2 Hydraulic

The American Bosch system tested is shown in Figure 7-5. It consisted of two-six gallon accumulators, an oil reservoir, an electric pump to pressurize the accumulators, the required hoses and fittings, and a hydraulic motor (hydrotor). The system as shown is approximately twice the size normally used in lifeboat diesel engine applications with starting temperature requirements of +20°F.

Starts below 0°F were not reliably achieved; at temperatures below -15°F starts were simply not possible; ether injection was used throughout these tests. At temperatures above +20°F, the hydraulic system produced reliable starts. The System did not produce enough cranking speed nor did the twelve gallons of accumulator capacity provide enough duration; the cranking period was limited to 10 to 15 seconds. Larger accumulator capacities were not considered because of the increased bulk and weight which would be difficult to accomodate in small lifeboats.

This system as tested was considerably heavier and bulkier than the other starting systems tested and also showed a high degree of ring gear abuse; this was due primarily to the high starter-impulse. Continued use of this particular system would have eventually damaged the engine starting ring-gear.

7.3.3 Pneumatic

The Ingersoll-Rand air system tested is shown in Figure 7-6. It consisted of a 60 gallon supply tank, a manual valve at the tank inlet, a quick opening 3/4" gas-cock valve, the necessary hoses and fittings, and an air motor. The manual and quick-opening valves were replacements for the normally supplied pilot-operated valves. Replacement by manually operated valves was necessary because of valve freezing at opera-

tions below $0^{o}F$. A 2HP compressor was used to replenish the air supply; a maximum starting air pressure of 120psig was used in all tests.

This system performed quite well at temperatures above $+20^{o}F$; at temperatures below that, however, starts were not possible. The 60 gallon supply tank produced cranking periods of 10 to 15 seconds; a larger capacity supply tank with its inherent longer cranking periods was not considered because it was felt that the additional size would prove too cumbersome in a lifeboat. Also, it was felt that additional measures were needed to prevent valve freezing below $0^{o}F$.

7.3.4 Electric

Components of the electric starter system are the: 1) motor, 2) switch, 3) pinion engaging mechanism, 4) the battery and 5) a battery charger. The starter is clearly shown in Figures 7-7 and 5-5 for the Lister and Farymann engines respectively. As previously mentioned, the battery is the weak link in the system and neither the Nickel Cadmium nor the lead-acid battery performed adequately below $+20^{o}F$. After the batteries were enclosed in an insulated plywood box and provided with a 75 watt heater pad which maintained the electrolyte temperatures in the range between 70 and $80^{o}F$, the system was found to operate consistently and reliably to ambient temperatures of $-30^{o}F$, the limit of the cold chamber.

This system, with battery heating provided, was found to be the most effective and reliable tested. It should be noted that the batteries were maintained in a fully charged condition for the majority of the tests. In the limited testing performed with a partially discharged but heated NiCad battery, no noticeable change in performance was observed. Methodical testing with varying degrees of battery discharge, however, was not performed.

7.4 Fuels and Lubricating Oil

Jet A-1(or JP-8) fuel was used in the majority of the tests; it is a kerosene grade distillate satisfying the requirements for low temperature diesel engine

starts. This fuel was selected because of its relatively low pour point, cloud point, and ignition temperature; other arctic grade fuels would also have been acceptable.

The Jet A-1 fuel exhibited no significant changes in characteristics down to temperatures of -30°F and performed quite well. The No.2 diesel fuel, on the other hand froze solidly at temperatures below -15°F and had significant ice formation around 0°F. This was observable in a beaker containing the fuels placed next to the fuel tanks. Engine starts with the No.2 fuel were impossible at the reduced temperatures without heating the fuel system and/or the engine. The No.2 fuel was used to assess the effects of fuel and coolant heaters as indicated in Table 6-1.

Although no difficulties were seen in the laboratory, a long term problem may exist in using JP-8 as diesel fuel; it is very thin and lacking in lubricity when compared to conventional diesel fuel. Fuel injection pumps have very close-fitting parts and depend upon fuel for lubrication of critical surfaces. Life boat service, however, is not severe and this factor may not be significant.

Other long term problems were not addressed, e.g., those normally related to storage and maintenance such as fungus and bacteria growth and ice crystal formation.

A number of commercially available engine oils were found to have both a desired low-temperature viscosity and good stability for long in-service life. These were in the main new, synthetic formulations. Since a number of products offered a high potential for low temperature performance, only one product, the Mobil Oil Company Delvac 1, was selected for confirmation. Test results were quite satisfactory. No significant decrease in cranking speed was seen.

7.5 Heaters

7.5.1 Air Heater

A small electric air blower with a 1500 watt heating coil was fitted to the Lister engine intake manifold to assess the effect of raising the temperature of the intake air. Air flows in the order of 10 CFM were produced. The tests were performed with and without ether injection and showed the air heater to be ineffective; engine starts were not substantially affected by air heating.

7.5.2 Battery Heater

A 75 watt, 110 volt battery heating pad was used inside an insulated box to heat the batteries and maintain electrolyte temperatures within a 70 to 80°F range; this has been previously discussed in Section 7.2 and 7.3.4 and shown in Figure 7.3. Under the test conditions, use of a thermostat to control the heating temperature was not necessary; for a typical application, however, a thermostat would be desireable to prevent overheating if inadvertedly left on during warm days.

Tests performed with the electrical starting system and a heated battery demonstrated a reliable system to temperatures of -30°F.

7.5.3 Coolant Heater

A 750 watt-110 volt coolant heater was used in both engines. The device is shown in Figure 7-8. It can also be partially seen on the Lister engine cart in Figure 5-4. It proved to be a very effective means for changing the engine environment. The procedure used in these tests was to allow the engine to cold soak to temperatures around -22°F and then to turn the coolant heater on and allow steady state conditions to be reached. On the Lister engine, the coolant temperature stabilized between 67 and 75°F; the oil temperature, by virtue of inherent conductive heating was raised from -22°F to a -10 to 0°F range; engine block temperature were in the order of 10 to 24°F. On the Farymann engine, the coolant temperatures stabilized at 125 to 150°F and the oil temperatures within +7 to +10°F.

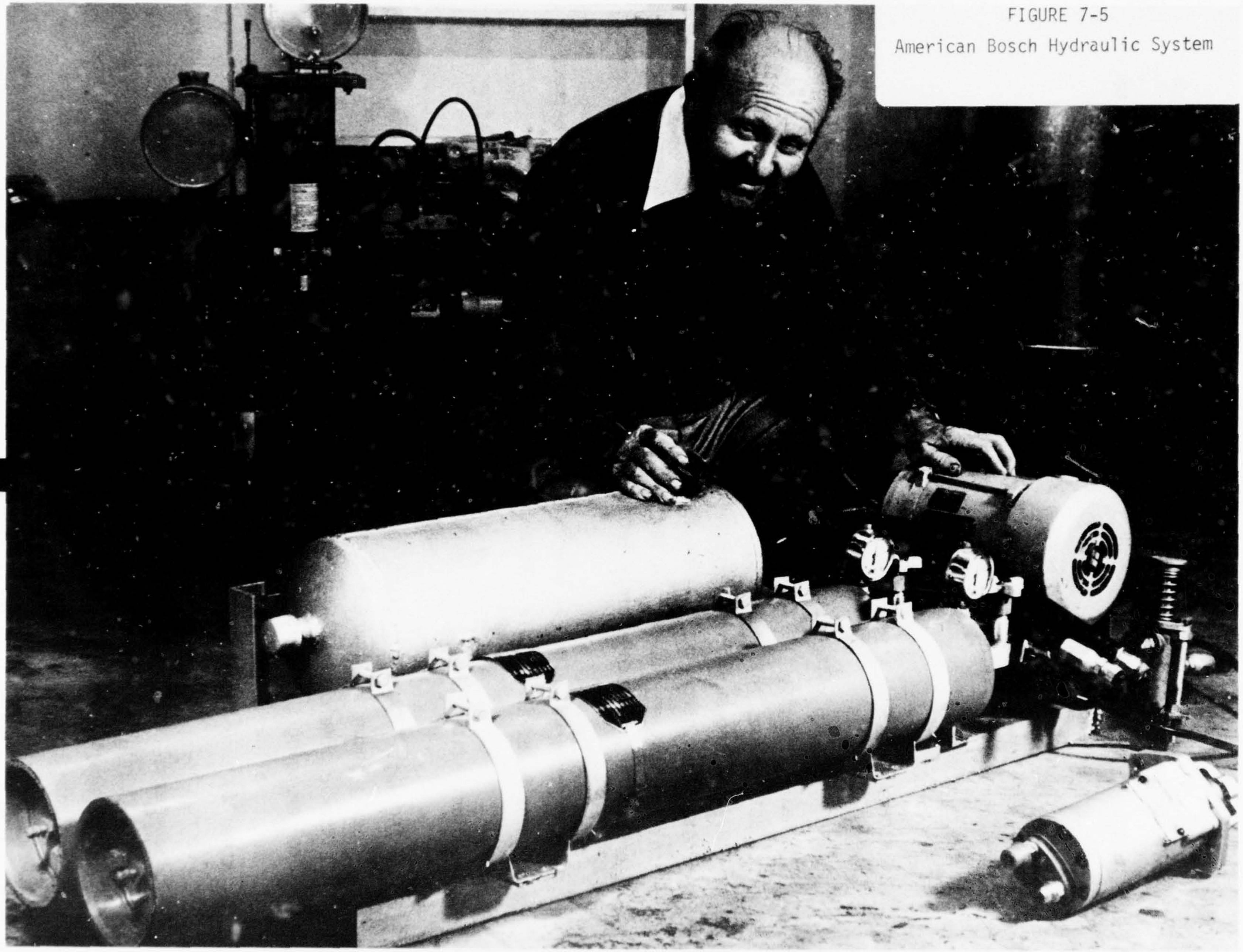


FIGURE 7-5
American Bosch Hydraulic System

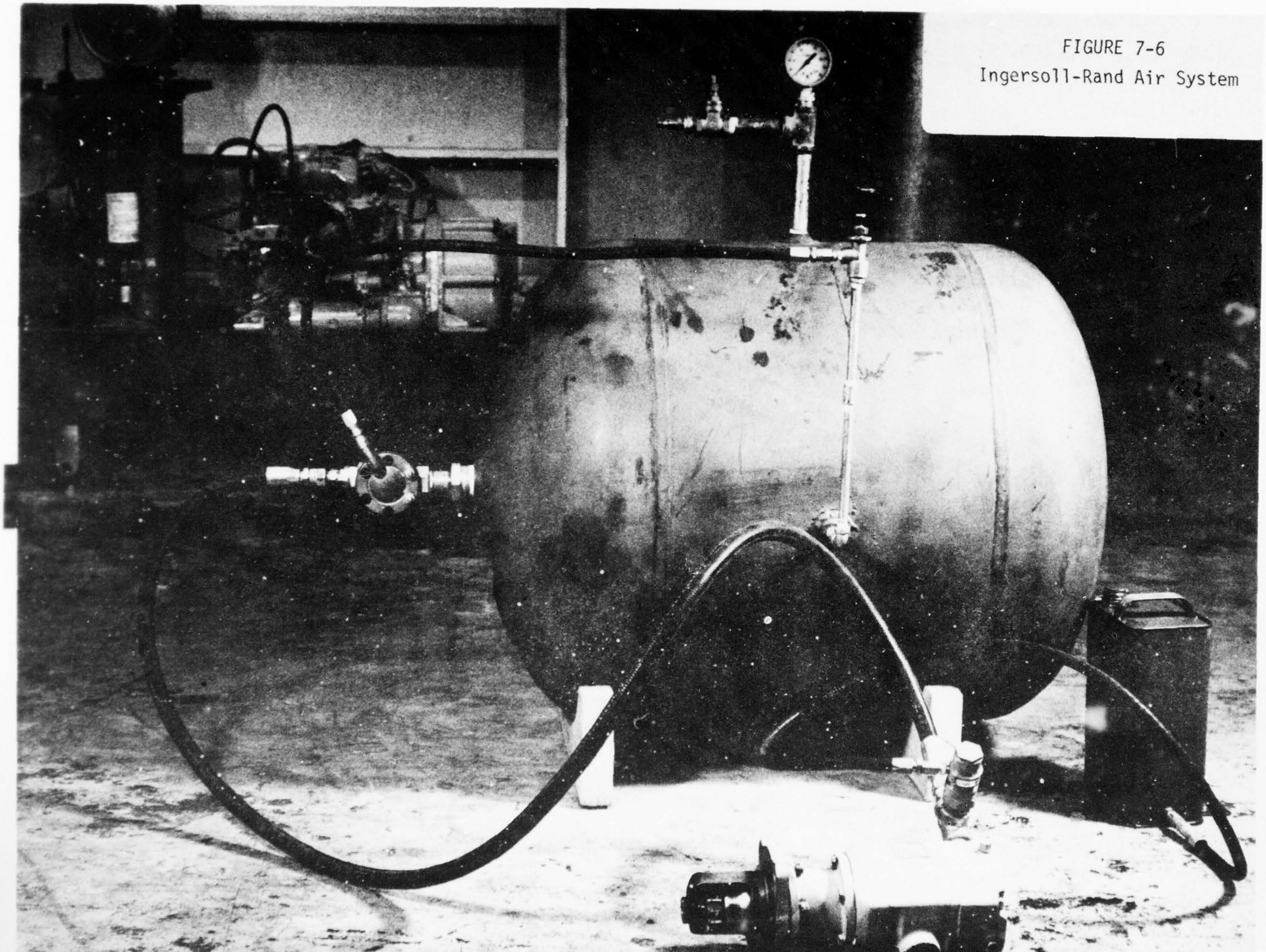


FIGURE 7-6
Ingersoll-Rand Air System

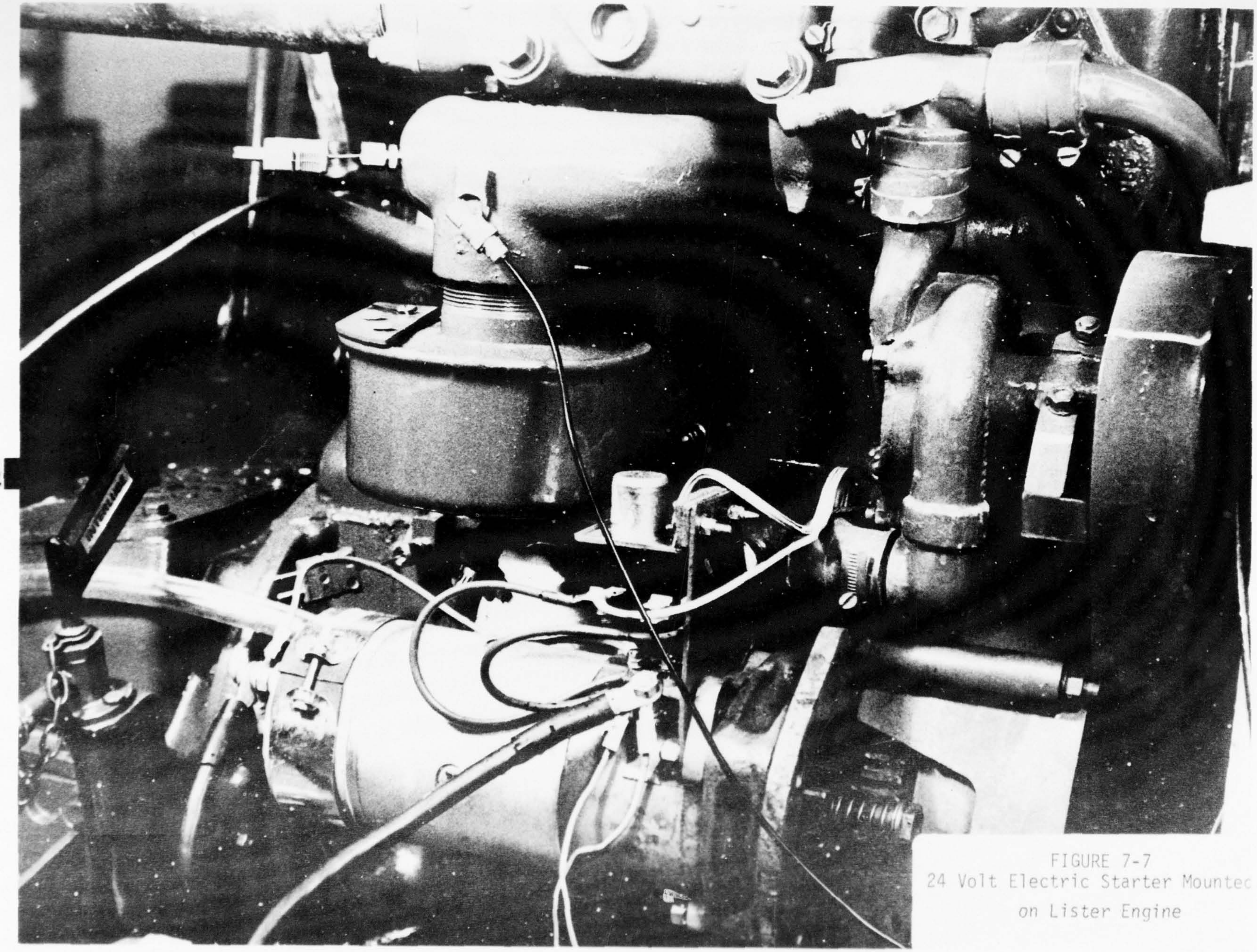


FIGURE 7-7
24 Volt Electric Starter Mountec
on Lister Engine

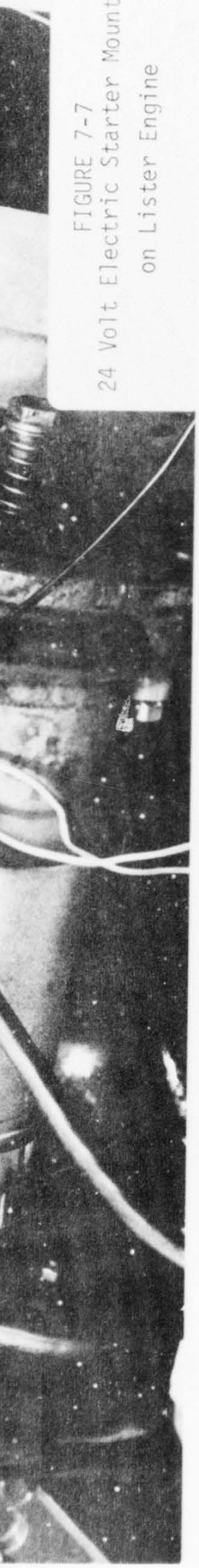


FIGURE 7-7
24 Volt Electric Starter Mountec
on Lister Engine

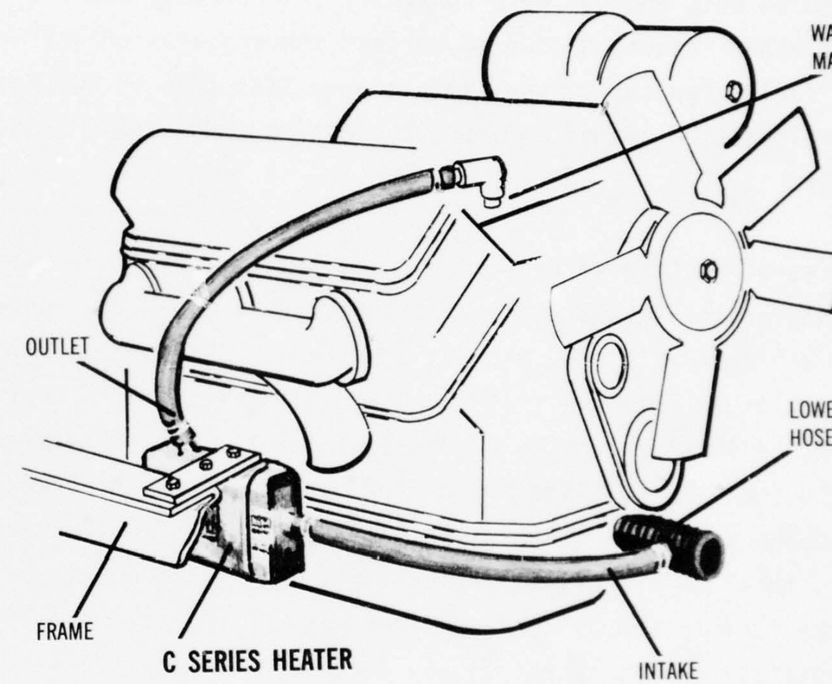


FIGURE 7-8 TYPICAL COOLANT HEATER

The primary reason for differences in final steady state temperatures between the engines resulted from their relative sizes, weights and cooling path lengths. Consequently the temperatures reached in the Farymann engine, the smaller of the two, were considerably higher than those reached in the Lister engine.

Engine starts on both engines were routinely and reliably achieved with and with out ether injection down to ambient temperatures of -22°F with the Jet A-1 fuel. Typical times-to-start were less than 10 seconds. The use of ether injection seemed to improve starting under these conditions only slightly.

Another series of tests were run in which No.2 diesel fuel was used in the Lister engine. With the ambient temperature in the -22°F range, starts were achieved within 10 seconds even though the fuel in the tank was frozen solidly. This was felt to be a peculiarity of the test set-up and not to be interpretted as a general finding. The test set-up was such that the fuel lines, filter, and fuel pumps were in such close proximity to the engine block that the No.2 fuel was sufficiently heated conductively to allow starting; once started, the engine continued to run until the fuel in the filter and lines was depleted. In typical lifeboat applications, it is not likely that No.2 diesel fuel or other non-artic grade fuels would function reliably in the temperature region around -22°F even with coolant heating.

7.5.4 Fuel Heating

A simple system was used to test the effectiveness of fuel heating; this was tried on the Lister engine only and is shown in Figure 7-9. The heating system consisted of two 150 watt coils wrapped around the fuel tank, a 150 watt coil wrapped around the fuel filter and 200 watts of flexible wrapping around the fuel lines; these heaters were powered by a 110 volt line acting through a switch. The procedure for test was similar to that used for coolant heaters; the engine was allowed to cold soak to temperatures around -22°F, thereby allowing the No.2 fuel to become a frozen solid, before turning the fuel heaters on; the fuel

temperature was than allowed to warm to a temperature range of 8 to 20^{o}F before attempting a start. With ether injection and a heated battery, starts could be achieved within 20 seconds.

7.6 Automatic Decompression System

The Farymann engine was provided with a very simple automatic decompression system; it consisted of a spur wheel riding on the threaded groove of a pulley fitted onto the main engine shaft; in the neutral position, the spur wheel caused the intake valves to be held open. As the shaft rotated, the spur wheel when physically removed from the neutral position would progress along the groove until 5 or 6 rotations had taken place and then would cause the intake valves to function normally. Use of this system, in contrast to not using decompression, actually increased the time-to-start of the engine by about a factor of two when using the electric starter; it was, however, still within the acceptable range of 10 seconds.

Tests indicated that this type of system provides no advantage with electrical starting. Under manual starting, however, it provides a valuable advantage for starting by one individual.

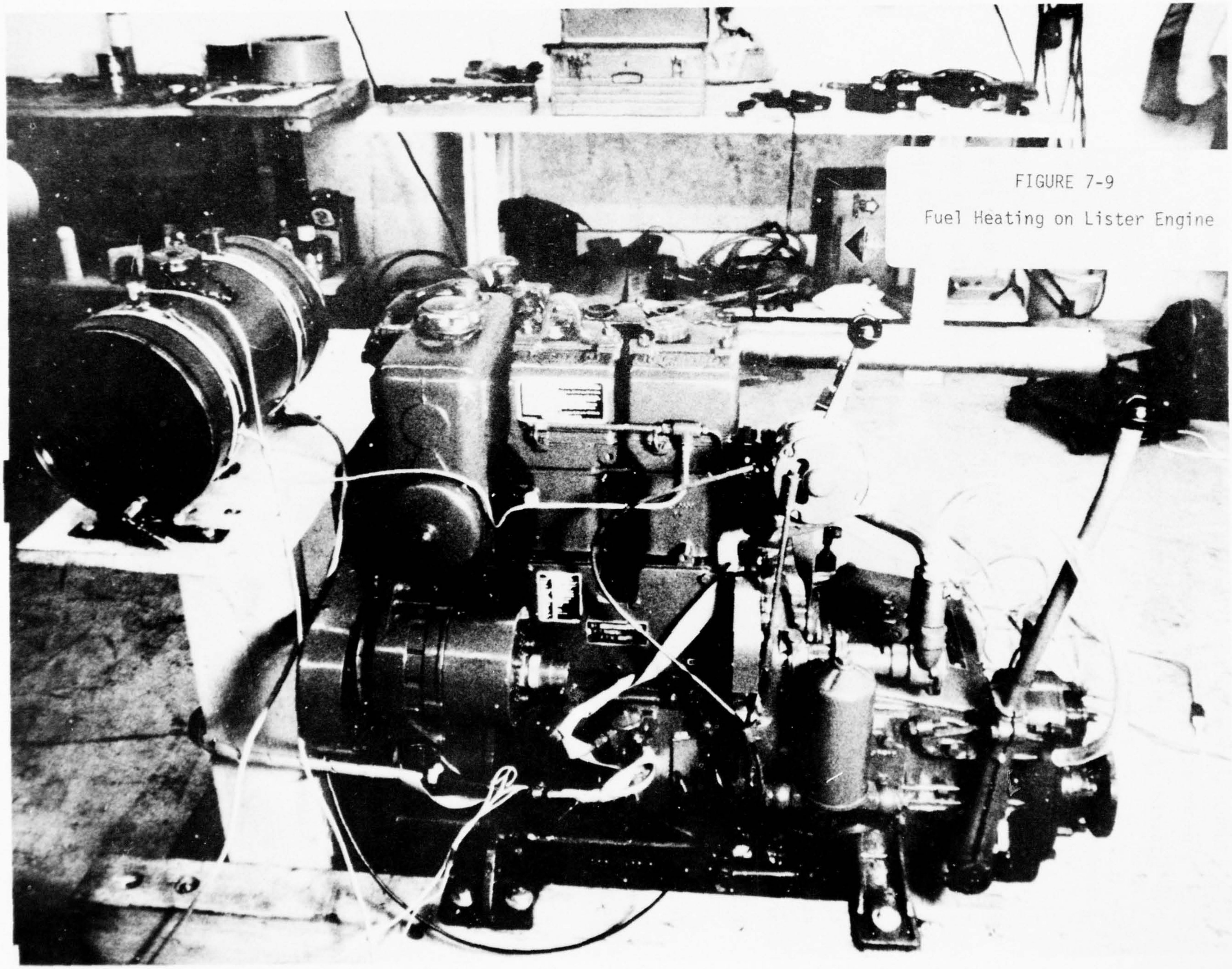


FIGURE 7-9

Fuel Heating on Lister Engine

8. Conclusions

Tests conducted during the laboratory evaluation phase have confirmed that conventional lifeboat diesel installations, fuels and lubricants are not suitable for operation at low temperatures. Starting difficulty was seen to begin at approximately +20°F and was impossible at -22°F, the test objective. The sources of difficulty were found to be fuel, lubricating oil and starter systems. Engines tested, however, were found to be quite suitable after modification.

As a result of the product survey and evaluation program at least one type of fuel, lubricating oil and starting aid system is known to function properly to -22°F or colder. These are: Aviation fuel A-1 (or JP-8), Mobil DELVAC 1 Synthetic oil, and either the Turner or KBI ether injection system. Other acceptable fuels and lubricants exist but were not evaluated because of the limited scope of this investigation.

The most effective starting system tested for the intended application was found to be a 24 volt electric system with a heated battery. In the test set-up, a simple, insulated plywood box containing the battery and a commercially available 75 watt heating pad provided sufficient heat such that either the Nickel Cadmium or the lead acid battery performed well. The selection of the battery type to be used in lifeboat applications should be based on the long term reliability expected, keeping in mind the following factors: 1) the life cycle cost of the NiCad battery will be about three times that of the lead acid battery, 2) the NiCad battery is larger and heavier, 3) sub-freezing temperatures in the electrolyte of the NiCad do not produce damage nor loss of capacity when re-warmed, 4) the NiCad battery, in contrast to the lead acid, has an unlimited shelf life, 5) the NiCad battery does not fail catastrophically and does so in a gradual fashion, and 6) the service life of the NiCad, pocket plate battery is over 20 years. Both battery types require a charger; the NiCad battery can use a conventional charger provided the voltage settings are properly adjusted.

The starter system voltage was raised from 12 to 24 volts as a result of diesel engine manufacturer's recommendations and the reported findings of U.S. Navy researchers (references 13 and 14). This change is seen to benefit the second of the dual objectives: that is, a cold-start after the lifeboat has been underway for some time and is no longer able to draw from ship's power for heating.

With battery heating, the conventional installed system (12 volts) would undoubtedly be adequate if the other modifications recommended in this report were also made.

The ether-injection starting aid system was found to be essential for cold-starts. Particularly if an engine coolant heater were not installed or inoperative. With coolant heating, starting was seen to be quicker.

It should be noted that test engines were factory new and in perfect condition. Existing engines for retrofit in the field should be provided with an extra margin of capability over that minimally found necessary in the laboratory tests.

To that end, coolant heating, while not found to be absolutely essential for cold-starts to -22^{o}F in the laboratry, is recommended for practical installations. Coolant heaters are simple, easy to maintain and install, relatively inexpensive, and are of a fail-safe nature; they provide the single, most effective means for altering the engine environment and faciliting cold engine starting.

8.1 Conclusion, Recommendation Summary

To satisfy the dual objective of:

1) starting lifeboat diesel engines reliably at -22^{o}F using starting aids and ship's power and
2) starting lifeboat diesel engines reliably at ambient temperature of +20^{o}F when ship's power is not available,

the following measures are recommended:

1) A 24 volt electric starter system with provisions for maintaining battery temperatures in the 70 to 80^{o}F range should be used. The battery type should be selected as a result of a detailed trade-off study and should include consideration of aircraft spill-proof type and battery caps which will prevent loss of electrolyte under any conceivable boat position, including inversion. Such caps are spring-loaded closed and relieve gas pressure as needed and effectively provide necessary sealing along with access for electrolyte replenishment. Batteries should be sized for starting at +20^{o}F. Dedicated battery chargers with trickle charge capability are required. These devices become part of the ship system.
2) Arctic grade diesel fuel should be used. In the tests, Aviation fuel A-1 (or JP8) was used successfully. Care should be taken to maintaining a clean fuel by both a careful system design and proper maintenance procedures, e.g,, means to provide tank stripping should be provided.
3) An SAE 5W lubricating oil should be used. Starting tests in the CASDE laboratory produced excellent results with the Mobil Delvac 1 synthetic oil.
4) An ether type injection system should be used comparable to either the Turner Quick Start or the KBI Diesel Start systems.
5) Engine coolant heaters should be used (closed coolant systems) and sized for the appropriate engine. KIM Hotstart 750 watt heaters were used in the laboratory with very good results.
6) A device to prevent arcing when connecting or disconnecting the ship's electrical power system to the boat engine and battery heating systems should be used. The system could be designed such that power is not applied to the connector until the connection is secure and removed be-

fore the connection is broken. Such a system would employ an explosion-proof magnetic controller, as used for large motor starting, to turn power on and off the umbilical cable to the boat. A sensing line built into the cable would control the controller holding coil. Two small explosion-proof switches in the umbilical connector actuated by insertion into the boat receptacle would enable (or disable) the controller holding coil. Two sensing switches, arranged in series, resolve the ambiguity of insertion and withdrawal. One switch actuates as the connector is inserted into receptacle case, but before the power pins make contact. The second switch is actuated after the pins are well seated in their mating sockets. Since both switches must actuate to enable the holding coil, it is not possible to turn power on unless the pins are well seated. Moreover on disconnecting, the holding circuit opens before the pins have left their sockets. The effect is to disable power before either connecting or disconnecting the heavy current contacts.

A suitable delay to prevent "jerking" out the connector and opening the main contacts before the holding coil drops out can be assured by requiring the connector to be twisted after insertion and before seating the pins. On rapid withdrawal the pins would not be separated without twisting the connector and after one of the series switches has released the holding coil.

7) Cooling water should be mixed with an anti-freeze solution to prevent freezing at temperatures to -30^{o}F or less.
8) A simple means for manually starting the engines should be provided as a backup. The method should allow starting by an untrained individual of normal size. Backup manual starting requirements should be imposed with ambient temperatures of 20^{o}F but not necessarily at the lower temperatures. It is felt that only one of the engines tested could have satisfied these requirements (Farymann engine) even though a serious effort to determine this was not made.
9) A means for assessing power and system status at the lifeboat station should be provided. This could range from a very simple system employ-

ing visual indication of status at the lifeboat to one employing both visual and audio alarms at the bridge of the ship.

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APPENDIX A

Sample Test Records

TEST DATA

TEST NO. ______

DATE-TIME: ______

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [ ] OFF [✓]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (^{O}F)

BATTERY ELECTROLYTE: −18.0

ENGINE OIL : −23.0

ENGINE BLOCK : −22.0

COOLANT : −22.0

CHAMBER AIR : −23.0

FUEL TANK : −22.6

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: —

START: YES [ ] NO [✓]

REMARKS:

BATTERY FROZEN. WOULD NOT CRANK ENGINE

TEST DATA

TEST NO. ____
DATE-TIME: ____

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☐ OFF

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+55.0
ENGINE OIL :	-27.0
ENGINE BLOCK :	-27.0
COOLANT :	-24.0
CHAMBER AIR :	-27.5
FUEL TANK :	-26.5

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 30

START: YES ☑ NO ☐

REMARKS:

USED A WARM BATTERY BROUGHT IN FROM AMBIEN[T]
TO CHECK ENGINE START. ELIMINATED EFFECT OF COLD-
BATTERY. BATTERY HEATING OR ELECTROLYTE CHANGE
APPEARS NECESSARY

TEST DATA

TEST NO. ________

DATE-TIME: ________

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☐ OFF ☑

STARTER TYPE: Electric

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE: -9.0

ENGINE OIL : -20.8

ENGINE BLOCK : -22.4

COOLANT : -23.6

CHAMBER AIR : -24.8

FUEL TANK : -23.2

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: ________

START: YES ☐ NO ☑

REMARKS:

TEST DATA

TEST NO. ________

DATE-TIME: 9-25-78

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☐ OFF ☑

STARTER TYPE: Electric

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+12.4
ENGINE OIL :	-23.0
ENGINE BLOCK :	-22.6
COOLANT :	-22.4
CHAMBER AIR :	-22.4
FUEL TANK :	-22.4

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: 60

START: YES ☐ NO ☑

REMARKS:

ENGINE HAD ADEQUATE CRANKING & SHOULD HAVE SHOWN SOME STARTING ATTEMPT — SUSPECT A FUEL-FLOW PROBLEM.

TEST DATA

TEST NO. 9-29-78

DATE-TIME: ______

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [ ] OFF [✓]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: -11.4

ENGINE OIL : -24.0

ENGINE BLOCK : -24.2

COOLANT : -24.2

CHAMBER AIR : -24.6

FUEL TANK : -24.2

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: —

START: YES [ ] NO [✓]

REMARKS:

BATTERY DEAD - WOULD NOT CRANK

TEST DATA

TEST NO. 10-1-78

DATE-TIME: ________

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [ ] OFF [✓]

STARTER TYPE: Electric

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: +20.8

ENGINE OIL : -23.2

ENGINE BLOCK : -22.8

COOLANT : -22.4

CHAMBER AIR : -24.6

FUEL TANK : -22.8

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 12.0

START: YES [✓] NO [ ]

REMARKS:

Battery Temp. Purposely Taken At 20.8°F To Confirm Capability To Start After Prolonged Boat Layoff In +30°F Water & -22°F Ambient Engine Started Successfully.

TEST DATA

TEST NO. ____________

DATE-TIME: 10-5-78

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☐ OFF ☑

STARTER TYPE: Electric

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE: +20.8

ENGINE OIL : -22.4

ENGINE BLOCK : ~~-21.8~~ -22.2 RDJ.

COOLANT : -21.8

CHAMBER AIR : -23.6

FUEL TANK : -23.2

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 35 Sec

START: YES ☑ NO ☐

REMARKS:

Successful Start. Test made to check start capability at ≈ +20°F battery temp.

TEST DATA

TEST NO. ______

DATE-TIME: 10-11-78

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☐ OFF ☑

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+19.0
ENGINE OIL :	-21.8
ENGINE BLOCK :	-21.6
COOLANT :	-19.2
CHAMBER AIR :	-21.6
FUEL TANK :	-22.0

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 7 SEC.

START: YES ☑ NO ☐

REMARKS:

STARTED OK.

TEST DATA

TEST NO. ______

DATE-TIME: 10-15-75

ENGINE: LISTER [x] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: Air

COOLANT HEAT: ON [ ] OFF [x]

FUEL HEAT: ON [ ] OFF [x]

AUTO DECOMPRESSION: ON [ ] OFF [x]

AIR HEAT: ON [ ] OFF [x]

FUEL TYPE: JP-8 [x] No.2 DIESEL [ ]

ETHER INJECTION: ON [x] OFF [ ]

TEMPERATURES (^{0}F)

BATTERY ELECTROLYTE: N/A

ENGINE OIL : -31.0

ENGINE BLOCK : -31.0

COOLANT : -31.0

CHAMBER AIR : -30.4

FUEL TANK : -31.2

STARTING-AIR PRESSURE

START 100PSI FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: —

START: YES [ ] NO [x]

REMARKS:

WOULD NOT START. TURNED OVER VERY SLOWLY — TOO SLOW TO START.

TEST DATA

TEST NO. ________

DATE-TIME: 10-15-78

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: AIR

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: —

ENGINE OIL : -28.6

ENGINE BLOCK : ~~-14.0~~ -21.8 RDT

COOLANT : -14.0

CHAMBER AIR : 0.0

FUEL TANK : -23.0

STARTING-AIR PRESSURE

START 100 FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: TO PRESSURE EXHAUSTION

START: YES [ ] NO [✓]

REMARKS:

TURNED OVER VERY SLOWLY. NO START

TEST DATA

TEST NO. ________

DATE-TIME: 10-17-78

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: AIR

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	—
ENGINE OIL :	+1.0
ENGINE BLOCK :	+1.6
COOLANT :	+1.2
CHAMBER AIR :	+4.4
FUEL TANK :	+1.6

STARTING-AIR PRESSURE

START 100 FINISH ____

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 6 SECS.

START: YES [✓] NO [ ]

REMARKS:

STARTED OK.

TEST DATA

TEST NO. ________

DATE-TIME: 10-18-78 6:00 AM

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [✓] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [✓]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	-19.0
ENGINE OIL :	-19.2
ENGINE BLOCK :	-19.0
COOLANT :	-19.6
CHAMBER AIR :	-17.6
FUEL TANK :	-19.4

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: -

START: YES [ ] NO [✓]

REMARKS:

NO START OR ATTEMPT AT STARTING — MAY BE A FUEL PROBLEM

TEST DATA

TEST NO. ________

DATE-TIME: 10-19-78
6:30 AM

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☑ NI-CAD ☐ BATTERY HEAT: ON ☐ OFF ☑

STARTER TYPE: ____________

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE:	32.2
ENGINE OIL :	31.0
ENGINE BLOCK :	31.2
COOLANT :	31.6
CHAMBER AIR :	33.2
FUEL TANK :	32.0

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 5

START: YES ☑ NO ☐

REMARKS:

STARTED OK.

TEST DATA

TEST NO. ________

DATE-TIME: 10-19-78
6 15 PM

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [✓] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [✓]

STARTER TYPE: Electric

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE: 21.5

ENGINE OIL : 27.4

ENGINE BLOCK : 27.2

COOLANT : ~~23.4~~ 24.5 RDJ.

CHAMBER AIR : 20.6

FUEL TANK : 27.4

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 7

START: YES [✓] NO [ ]

REMARKS:

STARTED OK

TEST DATA

TEST NO. ________

DATE-TIME: 10-22-78 11:30 AM

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [✓] NI-CAD [ ] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE: +92.4

ENGINE OIL : -25.0

ENGINE BLOCK : -26.0

COOLANT : -26.8

CHAMBER AIR : -27.0

FUEL TANK : -26.4

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 15 SEC.

START: YES [✓] NO [ ]

REMARKS:

STARTED OK. W/BATTERY HEAT.
NO START ON FIRST TRY. FOUND ETHER LINE PARTED AT INTAKE JET. AFTER FIX STARTED IN 15 SECS.

AD-A072 702 CASDE CORP TORRANCE CA F/G 21/7
STUDY TO IMPROVE THE STARTING PROBABILITY OF LIFEBOAT DIESEL EN--ETC(U)
FEB 79 R M DIJULIO, R SAUCEDO DOT-CG-74133-A
UNCLASSIFIED USCG-D-19-79 NL

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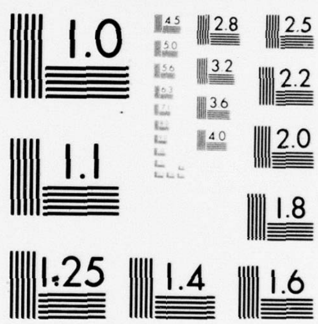

MICROCOPY RESOLUTION TEST CHART

TEST DATA

TEST NO. ______

DATE-TIME: 10-23-78 6^15 AM

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+81.2
ENGINE OIL :	-30.0
ENGINE BLOCK :	-30.5
COOLANT :	-30.4
CHAMBER AIR :	-30.2
FUEL TANK :	-30.1

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: 12 Sec

START: YES ☑ NO ☐

REMARKS:

STARTED OK. -30°F w/BAT. HEAT.

TEST DATA

TEST NO. ______

DATE-TIME: 10-25-75

ENGINE: LISTER [x] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [x] BATTERY HEAT: ON [x] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [x] OFF [ ]

FUEL HEAT: ON [ ] OFF [x]

AUTO DECOMPRESSION: ON [ ] OFF [x]

AIR HEAT: ON [ ] OFF [x]

FUEL TYPE: JP-8 [x] No.2 DIESEL [ ]

ETHER INJECTION: ON [x] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	85.4
ENGINE OIL :	-16.2
ENGINE BLOCK :	-6.6
COOLANT :	28.4
CHAMBER AIR :	-25.0
FUEL TANK :	—

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: 11 Sec.

START: YES [x] NO [ ]

REMARKS:

START OK. W/BAT HEAT & W/COOLANT HEAT @ -25°F. COOLANT TEMP. WAS NOT HIGH ENOUGH. SUSPECTED AIR BUBBLE IN COOLANT LINE TO ENGINE. INSTALLED TRANSPARENT HOSES & CONFIRMED BUBBLE. RELOCATED TAP TO ENGINE BELOW COOLANT SURFACE (LEVEL)

TEST DATA

TEST NO. ______

DATE-TIME: 10-25-78

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: ______

COOLANT HEAT: ON ☑ OFF ☐

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	81.6
ENGINE OIL :	3.2
ENGINE BLOCK :	–
COOLANT :	135.0
CHAMBER AIR :	-25.0
FUEL TANK :	–

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 4 Secs

START: YES ☑ NO ☐

REMARKS:

Good fast start at -25°F

TEST DATA

TEST NO. ________

DATE-TIME: 10-29-75

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: ____________

COOLANT HEAT: ON ☑ OFF ☐

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☐ OFF ☑

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	75.2
ENGINE OIL :	6.2
ENGINE BLOCK :	–
COOLANT :	142.8
CHAMBER AIR :	-21.2
FUEL TANK :	–

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 4 Sec.

START: YES ☑ NO ☐

REMARKS:

FAST START @ -21.2°F NO ETHER

TEST DATA

TEST NO. ______

DATE-TIME: 10-30-78

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON ☑ OFF ☐

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	75.6
ENGINE OIL :	-11.4
ENGINE BLOCK :	10.0
COOLANT :	63.2
CHAMBER AIR :	-29.8

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 5.5 Sec

START: YES ☑ NO ☐

REMARKS:

GOOD QUICK START WITH BATTERY & ENGINE HEATERS ON.

TEST DATA

TEST NO. ______

DATE-TIME: ______

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: Electric

COOLANT HEAT: ON ☑ OFF ☐

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☑ OFF ☐

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☐ OFF ☑

TEMPERATURES (°F)

BATTERY ELECTROLYTE	:	78.8
ENGINE OIL	:	8.2
ENGINE BLOCK	:	-
COOLANT	:	138.6
CHAMBER AIR	:	-20.8

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: No Start On ADC. 3 Sec w/o ADC

START: YES ☑ NO ☐

REMARKS:

First Try: Used ADC w/o Ether — No Start

Second Try: Disconnected ADC Started in 3 Secs.

ADC was Frozen & Did Not Come Out Of D/C.

TEST DATA

TEST NO. ____

DATE-TIME: 11-7-78

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: Electric

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☐

AUTO DECOMPRESSION: ON ☑ OFF ☐

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE: 76.8

ENGINE OIL : -25.6

ENGINE BLOCK : -

COOLANT : -25.8

CHAMBER AIR : -25.0

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 57 Sec.

START: YES ☑ NO ☐

REMARKS:

STARTED AFTER ADC RAN ITS COURSE

TEST DATA

TEST NO. ________

DATE-TIME: 11-4

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [✓] OFF [ ]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	79.4
ENGINE OIL :	-11.8
ENGINE BLOCK :	1.6
COOLANT :	23.2
CHAMBER AIR :	-19.0

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 1 Sec.

START: YES [✓] NO [ ]

REMARKS:

CHECK START MADE TO TEST AIR HEATER & ETHER SHOT. DID NOT EXPLODE OR BURN. ENGINE TEMPS. NOT STABILIZED PROPERLY. WILL REPEAT TEST LATER.

TEST DATA

TEST NO. ______

DATE-TIME: 11-7-85 6:30pm

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: Electric

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☑ OFF ☐

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE: 90.8

ENGINE OIL : -21.2

ENGINE BLOCK : -23.2

COOLANT : -23.8

CHAMBER AIR : -25.0

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 10 Secs.

START: YES ☑ NO ☐

REMARKS:

Air heater motor frozen. Lack of air flow burned up heating elements. Engine started anyway after 10 sec cranking.

TEST DATA

TEST NO. ________

DATE-TIME: 11-4-78

ENGINE: LISTER [ ] FARYMANN [x]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [x] BATTERY HEAT: ON [x] OFF [ ]

STARTER TYPE:

COOLANT HEAT: ON [ ] OFF [x]

FUEL HEAT: ON [ ] OFF [x]

AUTO DECOMPRESSION: ON [x] OFF [ ]

AIR HEAT: ON [ ] OFF [x]

FUEL TYPE: JP-8 [x] No.2 DIESEL [ ]

ETHER INJECTION: ON [x] OFF [ ]

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE: 79.8

ENGINE OIL : -24.8

ENGINE BLOCK : -

COOLANT : -24.2

CHAMBER AIR : -21.8

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 10 Sec.

START: YES [x] NO [ ]

REMARKS:

Started in 10 sec w/ADC. Repeated test in 10 minutes. Second time, started in 8 secs w/o ADC. Used ether both times.

TEST DATA

TEST NO. ______

DATE-TIME: 11-7-78

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: HYDRAULIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE	:	-
ENGINE OIL	:	-28.2
ENGINE BLOCK	:	-29.2
COOLANT	:	-29.8
CHAMBER AIR	:	-29.6

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START 3000 FINISH 1500

STARTING (CRANKING) TIME SECS: 18 Sec.

START: YES [ ] NO [✓]

REMARKS:

WOULD NOT START. TRIED 4 TIMES. CRANK SPEED TOO LOW

TEST DATA

TEST NO. ________

DATE-TIME: 11-7-78 6:15 PM

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: HYDRAULIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: -

ENGINE OIL : -25.8

ENGINE BLOCK : -25.8

COOLANT : -25.2

CHAMBER AIR : -29.2

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START 3000 FINISH 1500

STARTING (CRANKING) TIME SECS: 20 SEC.

START: YES [ ] NO [✓]

REMARKS:

WOULD NOT START. CRANKED TO EXHAUSTION OF ACCUMULATOR PRESSURE. STILL SEEMS TO TURN TOO SLOWLY.

TEST DATA

TEST NO. ________

DATE-TIME: 11-8-78

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☐ BATTERY HEAT: ON ☐ OFF ☐

STARTER TYPE: Hydraulic

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE: -

ENGINE OIL :

ENGINE BLOCK : -16.4

COOLANT : -16.4

CHAMBER AIR : -17.0

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START 3000 FINISH 1500

STARTING (CRANKING) TIME SECS: 30 Secs.

START: YES ☐ NO ☑

REMARKS:

Would Not Start.

TEST DATA

TEST NO. ________

DATE-TIME: 11-12-8

ENGINE: LISTER [x] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [x] BATTERY HEAT: ON [x] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [x]

FUEL HEAT: ON [ ] OFF [x]

AUTO DECOMPRESSION: ON [ ] OFF [x]

AIR HEAT: ON [ ] OFF [x]

FUEL TYPE: JP-8 [x] No.2 DIESEL [ ]

ETHER INJECTION: ON [ ] OFF [x]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+87.0
ENGINE OIL :	-21.0
ENGINE BLOCK :	-21.0
COOLANT :	-21.6
CHAMBER AIR :	-20.4

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: –

START: YES [ ] NO [x]

REMARKS:

ENGINE WOULD NOT START W/O ETHER. WITH ETHER ENGINE STARTED IN 12 SECS.

TEST DATA

TEST NO. ______

DATE-TIME: 11-20-8

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [✓] OFF [ ]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [ ] No.2 DIESEL [✓]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+81.6
ENGINE OIL :	-20.0
ENGINE BLOCK :	-20.8
COOLANT :	-21.2
CHAMBER AIR :	-23.4
FUEL TANK :	7.8

STARTING-AIR PRESSURE

START — FINISH —

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: 23 Sec

START: YES [✓] NO [ ]

REMARKS:

Used No. 2 Diesel Fuel w/ fuel heat.
Fuel warmed to 7.8 from -21.4°F. Started in 23 Secs

TEST DATA

TEST NO. ________

DATE-TIME: 11-12-8

ENGINE: LISTER [ ] FARYMANN [✓]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: Electric

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [✓] OFF [ ]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE:	+83.2
ENGINE OIL :	-20.0
ENGINE BLOCK :	-
COOLANT :	-20.0
CHAMBER AIR :	-20.4
FUEL TANK :	-

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 9 Sec

START: YES [✓] NO [ ]

REMARKS:

START IN 9 SEC USING ADC + TURNER QUICK START.

TEST DATA

TEST NO. ______

DATE-TIME: 11-12

ENGINE: LISTER [ ] FARYMANN [✓]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: Electric

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: + 82.6

ENGINE OIL : -20.6

ENGINE BLOCK : -

COOLANT : -20.4

CHAMBER AIR : -19.8

FUEL TANK : -

STARTING-AIR PRESSURE

START - FINISH -

HYDRAULIC SYSTEM PRESSURE

START - FINISH -

STARTING (CRANKING) TIME SECS: 4 Sec

START: YES [✓] NO [ ]

REMARKS:

Fast Start w/o ADC using Turned Quick Start.

TEST DATA

TEST NO. ______

DATE-TIME: 11-9-8

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [ ] BATTERY HEAT: ON [ ] OFF [ ]

STARTER TYPE: AIR

COOLANT HEAT: ON [ ] OFF [✓]

FUEL HEAT: ON [ ] OFF [✓]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [✓] No.2 DIESEL [ ]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE	:	—
ENGINE OIL	:	-23.8
ENGINE BLOCK	:	-24.6
COOLANT	:	-25.0
CHAMBER AIR	:	-28.2
FUEL TANK	:	—

STARTING-AIR PRESSURE

START 120 FINISH 15

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: —

START: YES [ ] NO [✓]

REMARKS:

CRANKED FOR 1 MINUTE. EXHAUSTED 60 GALLON TANK AIR SUPPLY. TOO SLOW TO START.

TEST DATA

TEST NO. ________

DATE-TIME: ________

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☐ BATTERY HEAT: ON ☐ OFF ☐

STARTER TYPE: AIR

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	—
ENGINE OIL :	-19.4
ENGINE BLOCK :	-16.6
COOLANT :	-15.6
CHAMBER AIR :	-16.2
FUEL TANK :	—

STARTING-AIR PRESSURE

START 120 FINISH 10

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: —

START: YES ☐ NO ☑

REMARKS:

CRANKED TO AIR SUPPLY DEPLETION. TURNED TOO SLOW TO START.

TEST DATA

TEST NO. ________

DATE-TIME: ________

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☐ BATTERY HEAT: ON ☐ OFF ☐

STARTER TYPE: AIR

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☐ OFF ☑

TEMPERATURES (°F)

BATTERY ELECTROLYTE: ________

ENGINE OIL : +38.0

ENGINE BLOCK : +42.6

COOLANT : +49.0

CHAMBER AIR : +43.0

FUEL TANK : –

STARTING-AIR PRESSURE

START 120 FINISH 30

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: ________

START: YES ☐ NO ☑

REMARKS:

SPUN ENGINE FORCEFULLY FOR 15 SECS. CONTINUED SPINNING AT REDUCED RPM FOR ADDITIONAL 50 SECS. THEN STARTER STOPPED WITH AIR SUPPLY PRESSURE AT 30 PSIG.

TEST DATA

TEST NO. ________

DATE-TIME: 11-10-8

ENGINE: LISTER ☑ FARYMANN ☐

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☐ BATTERY HEAT: ON ☐ OFF ☐

STARTER TYPE: Air

COOLANT HEAT: ON ☐ OFF ☑

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (^{o}F)

BATTERY ELECTROLYTE	:	-
ENGINE OIL	:	+36.2
ENGINE BLOCK	:	+37.8
COOLANT	:	+40.0
CHAMBER AIR	:	+40.0
FUEL TANK	:	-

STARTING-AIR PRESSURE

START 120 FINISH 80

HYDRAULIC SYSTEM PRESSURE

START — FINISH —

STARTING (CRANKING) TIME SECS: 10 sec

START: YES ☑ NO ☐

REMARKS:

STARTED OK AT +40°F.

TEST DATA

TEST NO. ______

DATE-TIME: 11-23 8²⁰ pm

ENGINE: LISTER [✓] FARYMANN [ ]

TEST CONFIGURATION

BATTERY: LEAD-ACID [ ] NI-CAD [✓] BATTERY HEAT: ON [✓] OFF [ ]

STARTER TYPE: ELECTRIC

COOLANT HEAT: ON [✓] OFF [ ]

FUEL HEAT: ON [ ] OFF [·]

AUTO DECOMPRESSION: ON [ ] OFF [✓]

AIR HEAT: ON [ ] OFF [✓]

FUEL TYPE: JP-8 [ ] No.2 DIESEL [✓]

ETHER INJECTION: ON [✓] OFF [ ]

TEMPERATURES (°F)

BATTERY ELECTROLYTE: +71.2

ENGINE OIL : -5.8

ENGINE BLOCK : +19.2

COOLANT : +68.4

CHAMBER AIR : -22.2

FUEL TANK : –

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 4.0 Sec

START: YES [✓] NO [ ]

REMARKS:

FAST START: W/ETHER BATT & COOLANT HEAT "ON"

No.2 F.O.

TEST DATA

TEST NO. ________

DATE-TIME: 11-23 8:20 pm

ENGINE: LISTER ☐ FARYMANN ☑

TEST CONFIGURATION

BATTERY: LEAD-ACID ☐ NI-CAD ☑ BATTERY HEAT: ON ☑ OFF ☐

STARTER TYPE: Electric

COOLANT HEAT: ON ☑ OFF ☐

FUEL HEAT: ON ☐ OFF ☑

AUTO DECOMPRESSION: ON ☐ OFF ☑

AIR HEAT: ON ☐ OFF ☑

FUEL TYPE: JP-8 ☑ No.2 DIESEL ☐

ETHER INJECTION: ON ☑ OFF ☐

TEMPERATURES (°F)

BATTERY ELECTROLYTE:	+52.8
ENGINE OIL:	+7.8
ENGINE BLOCK:	–
COOLANT:	+126.8
CHAMBER AIR:	–22.2
FUEL TANK:	–

STARTING-AIR PRESSURE

START – FINISH –

HYDRAULIC SYSTEM PRESSURE

START – FINISH –

STARTING (CRANKING) TIME SECS: 2 Sec.

START: YES ☑ NO ☐

REMARKS:

Fast Start w/Ether Batt & Coolant Heat "On".
JP-8 Fuel.